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EXTENDED APOLLO SYSTEMS UTILIZATION STUDY

ADDENDUM 1

Final Report

Volume 1. Summary (U)

5 May 1965

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FOREWORD

This document constitutes a portion of the final report (SID 65-500) for Addendum 1 of Contract NAS9-3140, Extended Apollo Systems Utilization Study, dated 6 July 1964, prepared by the Space and Information Systems Division of North American Aviation, Inc. The analyses described herein and in the volumes listed below were conducted under the direction of the National Aeronautics and Space Administration's Manned Spacecraft Center as an addendum to the basic contract which included the Apollo X Study (SID 64-1860) and the Prolonged Missions Study (results to be published later). This final report has been prepared in a series of five volumes as follows:

1. Summary

2. Experiment Analysis and Requirements

   Part I: NASA Flights
   Part II: Air Force Flights
   Appendix A. NASA Experiments
   Appendix B. Air Force Experiments
   Appendix C. Mission Scheduling Computer Printout for NASA Flights

3. Configuration Analysis and Experiment Accommodation

   Appendix A. Engineering Drawings
   Appendix B. Air Force Missions

4. Subsystems Analysis

5. Development Planning

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TECHNICAL REPORT INDEX/ABSTRACT

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ADDENDUM 1, FINAL REPORT, VOLUME 1 (U)

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APOLLO EXTENSION SYSTEMS, SPACECRAFT/EXPERIMENT INTEGRATION, BLOCK II APOLLO, BLOCK IIA APOLLO, APOLLO X, APOLLO MODIFICATIONS, CONFIGURATION C, CONFIGURATION D, CONFIGURATION 1, CONFIGURATION D', RACK, PALLET, AUXILIARY MODULE

ABSTRACT

This report defines the design characteristics of four potential extended mission Apollo spacecraft designed to specific NASA mission and configuration requirements. All configurations are for Earth-orbital missions, which include low inclination, polar, and synchronous orbits and comprise a total of 15 NASA missions.

The four configurations studied present various degrees of modification to the Apollo Block II CSM. Configuration 1 is employed for 14-day missions and requires minimum modification. It may be used with either an experiments rack or pallet or both. Configuration C is identical to the Apollo X CSM and is utilized with an experiments rack for durations of up to 45 days. Configuration D is essentially a Block II CSM, with subsystems for life extension installed in the experiments rack. Additionally, an experiments pallet may be installed in the Configuration D CSM. Configuration D' is for 30-day missions and uses the Block II CSM as a baseline, similar to Configuration D. Early schedule requirements, however, dictate the prototype modification of critical subsystems in Configuration D' in order to meet the 30-day mission requirement.

The capability of each configuration was measured against the requirements dictated by 15 NASA-derived experimental packages. Additionally, the Air Force MOL experiments were examined and optimally grouped in a minimum number of flights. It was found that all NASA missions could be accommodated within the capabilities of the applicable configurations with certain revisions to experiment operation and/or mission duration to meet launch vehicle payload limits. All Air Force experiments could be accommodated in five flights.

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PREFACE

Over the past two years, a number of investigations have been performed to determine the characteristics of modifications required to extend the orbital duration of the Apollo spacecraft for alternate mission applications. Initial studies examined system characteristics for application as a 120-day Earth-orbital laboratory vehicle. Because of this extended duration, it was necessary that advanced subsystem concepts be employed in several cases to remain within the payload capabilities of the Saturn IB launch vehicle. Subsequent studies determined the characteristics of the Apollo CSM assuming restriction to use of only current Apollo subsystems concepts. Under this restriction, it was found that the Earth-orbital duration capability of the CSM was limited to approximately 90 days because of Saturn IB payload limits.

The recently concluded Apollo X study examined in depth the CSM characteristics and modifications required to perform NASA near-term missions of interest. These missions included both extended Earth-orbital and lunar-orbital mission durations of 45 and 34 days, respectively. Concurrent with the Apollo X study, separate contractors were examining the characteristics of: (1) the LEM ascent stage modified for use as an experiment module, and (2) an experimental laboratory module of new design.

Since the conclusion of the Apollo X study, several configuration innovations have been conceived by NASA which could warrant inclusion in the Apollo Extension Systems (AES) program. Two of these innovations take the form of experimental modular appendages and are identified as a "rack" and a "pallet"; the rack could be used in place of the modified LEM or a new laboratory module, and the pallet could be installed in the empty bay (Sector I) of the service module. Using these modular appendages, the alternate mission capability of the Block II Apollo could be increased through the addition of experiments as well as subsystems required for mission life extension beyond 14 days. It became apparent that further studies were warranted relative to (1) the comparative operational effectiveness of the various experimental appendages, and (2) the possible methods for extending the orbital duration capability of the CSM. The method selected to achieve orbital-life extension could actually result in varying degrees of CSM changes—depending upon the subsystem extension philosophy implemented.

A matrix of configurational approaches could readily be defined as only partially indicated in the accompanying chart, AES Concepts (Figure 1), with corresponding variations in costs, schedules, and operational capabilities. Therefore, in order to evaluate the characteristics and capabilities of each of the

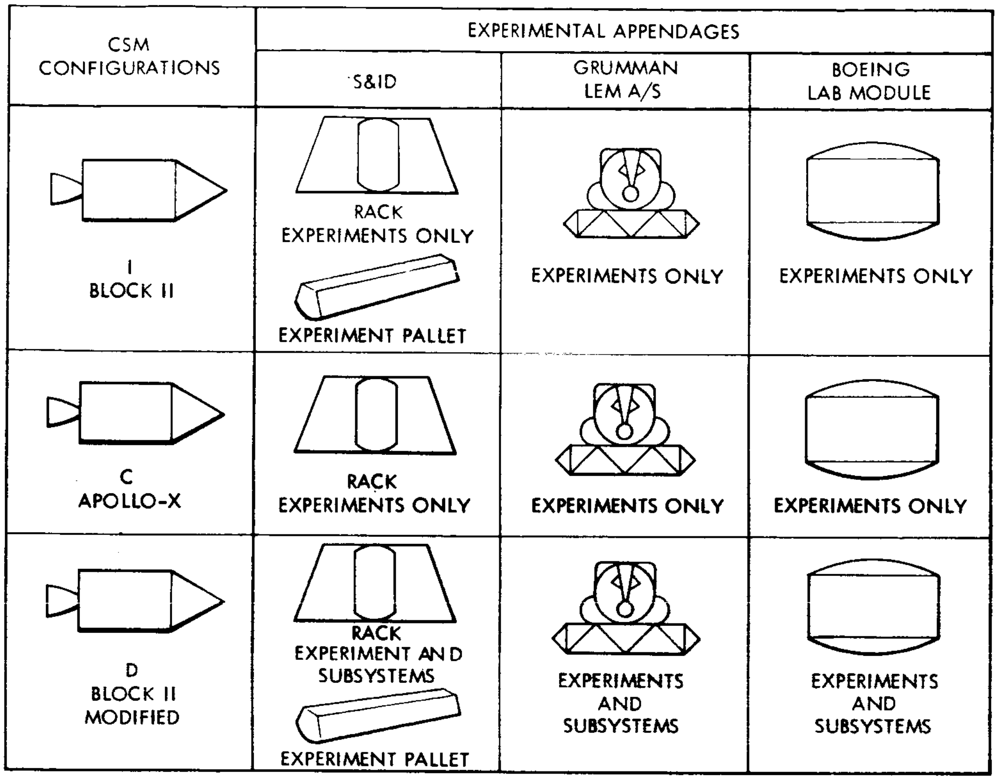

Figure 1. AES Concepts

possible combinations, parallel AES studies were initiated by NASA. S&ID was responsible for evaluating the characteristics of the CSM, rack, and pallet; Grumman and Boeing conducted separate studies of the LEM experimental module and new laboratory module design, respectively. The results of the three contractor studies were to be in a form such that the design and development characteristics of all possible system elements could be assembled by NASA into complete configurations and development programs of their own choosing.

The S&ID study was concerned with the examination of several basic configuration approaches, each of which represents varying degrees of Block II CSM modification, experimental capability, operational complexity, and program costs. These configuration approaches are defined as follows:

CONFIGURATION 1

By NASA definition, Configuration 1 is essentially the Block II CSM—without major changes, but with the addition of an experimental pallet (in SM Sector 1) and/or an experimental appendage (rack or laboratory module) docked to the CM during orbital operations. Orbital life is necessarily limited to 14 days or less since changes to the CSM subsystems are precluded. Subsystems support for the experiments—except for those in the pallet— is provided by the CSM.

CONFIGURATION C

Configuration C is identical to the CSM approach derived in earlier Apollo X studies where mission life extension to 45 days was achieved through the addition (in the CSM) of expendables, spares, and redundancies of Apollo Block II subsystems. Since the service module Sector 1 is occupied by subsystems in this approach, the pallet does not apply here. However, the rack or either of the laboratory modules would be included. As in Configuration 1, support of the experiments housed in the rack or laboratory module is provided by the subsystems located in the CSM.

CONFIGURATION D

Configuration D was to be based upon use of the Block II CSM with minimum modifications, in combination with an experiments/subsystems rack or laboratory module and with a pallet if required. Experiment support is provided by the CSM subsystems during the first 14 days (approximately) of orbital operation, after which subsystems life extension provisions installed on the (experimental appendages) would provide support both to the CSM and the experiments for the remainder of the 45-day orbital duration. By definition the subsystems installed on or in the experimental appendage were to be of the type defined under the prior Apollo X study; these included, for example, extended life fuel cells with in-space start, new cryogenic tankage, etc. During the early phases of the study, the Configuration D approach was modified through mutual agreement by NASA and S&ID at a series of weekly interface meetings. As a result, additional Configuration D ground rules were —of necessity—formulated which yielded a configuration that does not absolutely adhere to the requirement that the Block II CSM remain unchanged. More explicitly, revised Configuration D ground rules resulted in the installation of only the power system life-extension capability on the external device.

CONFIGURATION D′

Additionally, a requirement for one early 30-day mission (Flight 211), dictated the establishment of a unique approach—which was identified as Configuration D′ by S&ID. This configuration is similar to Configuration D with respect to subsystem location and general arrangement. However, in Configuration D′ the mission life-extension is provided by the use of only Block II subsystems that are "stretched" through prototype modifications to accomplish the required 30-day mission. The cryogenic storage system included on the rack, for example, is comprised of multiples of Block II cryogenic tanks rather than of the new and larger tanks defined in the Apollo X study.

A summary of characteristics of the four configurations of interest is presented in Table 1. A detailed definition of the vehicle and subsystems ground rules for each configuration may be found in appropriate volumes of this report.

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Table 1. Configuration Characteristics

		Configuration 1 (14 Days)	Configuration D' (30 Days)	Configuration C (45 Days)	Configuration D (45 Days)
Command Module	Structure	Block II	Block II	Block IIA	Block IIA
	Subsystems	Block II	Block II modified	Apollo X	Apollo X
	LiOH and crew systems	1 day	1 day	1 day	1 day
	Umbilical to rack				
Service Module	Structure	Block II	Block II	Block IIA	Block II modified
	Cryogenics	Block II	Block II	Apollo X	Block II
	Fuel cells	Block II	Block II	1000 hours	Block II
	RCS	Block II	Block II	As needed	As needed
	SPS tankage	Block II	Block II	As needed	Block II
	Sector I	Empty or pallet	LMS installation	EPS installation	Empty or pallet
Rack (external device)	Cryogenics	None	Block II	None	Apollo X
	Fuel cells	None	Block II modified	None	1000 hours
	LiOH and crew systems	13 days	29 days	44 days	44 days

The design approach for each configuration was based upon consideration of the application of a standard vehicle capable of performing the defined NASA missions and Air Force experiments. Additionally, CSM/external appendage interfaces were mutually defined among NASA, S&ID, Boeing, and Grumman such that the CSM for each appropriate configuration could be used alternately with either the rack, pallet, LEM laboratory or separate laboratory module without change. S&ID studies of the rack were also oriented toward providing a common rack design for all configurations and missions which would be capable of containing experiments, or experiments and subsystems as required.

The primary objective of the study was to define the characteristics and capabilities of various CSM/rack/pallet combinations as applied to experimental flight package and mission constraints defined by NASA. The actual grouping of each of 15 experimental flight packages was the responsibility of IBM under the direction of NASA. Consequently, S&ID's role in the NASA experiments area was limited to defining the configuration and subsystems requirements demanded by each of these experimental flight groupings as a basis for the experiment integration task. The Air Force individually specified experiments were integrated into similar, but separate, vehicles; however, the optimal grouping of these experiments—in order to minimize the number of flights required—was accomplished by S&ID.

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In order to assess the cost and schedule ramifications attendant upon each of the matrix considerations, development planning studies were performed based upon the NASA defined launch schedule (AE 65-1), which entails a total of 28 manned AES flights through the first quarter of 1972.

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INTRODUCTION

This volume presents a summary of all investigations conducted under the Apollo Extension Systems (AES) study. For convenience, the document has been divided into the major areas of study effort: (1) Experimental Analysis and Requirements, (2) Configurations and Experiments Accommodation, (3) Subsystems Analysis, and (4) Development Planning. A number of investigations revolved about the development and integration of specified Air Force MOL experiments, some of which carry a SECRET-LIMITED ACCESS classification. In order to permit wide distribution of this report, all information pertaining to the AF experiments analysis has been deleted and included in separate volumes. For more detail regarding any of the technical areas covered by this study, the reader should refer to other volumes as listed in the Foreword.

The overall study was primarily concerned with the integration of NASA-defined experimental packages into several postulated vehicle and subsystem configuration approaches, also defined by NASA. Consequently, the majority of the investigations were not conducted in a "normal" fashion where subsystem component selection, location, and optimal experimental groupings could be established based upon study-developed criteria. As a result, the major emphasis was placed upon examining the operational and technical ramifications attendant with previously established definitions.

Full application was made of data developed under the recently completed Apollo X study (NAS9-3140) which was similarly concerned with maximum Earth orbital mission durations of 45 days.

The development planning studies were also based upon a requirement to support a launch schedule (AE 65-1) established by NASA. In this area, therefore, major emphasis was directed toward examining associated manufacturing buildup, checkout schedules, costs, etc., required to meet this schedule rather than attempting to define, for example, the earliest flight date possible or to evaluate schedule variations.

EXPERIMENTAL ANALYSIS AND REQUIREMENTS

This phase of the study was directed toward the attainment of three objectives: demonstrate the operational compatibility of specified experiments with Apollo Extension System (AES) mission and performance parameters, examine the feasibility of accommodating these experiments in specified AES configurations, and conduct a preliminary integration analysis of assigned groupings of experiments on given flight missions.

The scientific or operational objectives, individual experiment designs, basic experiment groupings, and the assignment of these groups to flight missions were in accordance with NASA specifications cited for the series of 15 AES Earth-orbital flights considered. Design variations and engineering assumptions were allowed—within the overall constraint that there would be no deviation from NASA-specified experimental objectives. With the exception of relatively minor additions to NASA-specified designs, this study has not included any experimental design effort. Physical accommodation was defined to the preliminary design level as necessary to confirm packaging and performance feasibility, using specified equipment data whenever possible. Standardization and minimum modification were sought throughout the study. The study was conducted under the following broad ground rules:

- All flights are assumed to have three crewmen available, with commensurate experimental volume in the command module
- All flight groupings include the biomedical, behavioral, and radiation-monitoring experiments specified by NASA
- The experimental accommodation sequence for each flight is:
    1. Conduct all experiments in the command module, if possible
    2. If this is not possible. attempt to accommodate the full program by adding an experimental pallet to Sector 1 of the service module
    3. If even this additional area does not suffice, substitute the experimental rack for the pallet and again attempt integration
    4. If still not feasible, use both pallet and rack

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For certain cases, the reduction of experiment frequency or flight duration is permitted as long as maximum accomplishment of flight objectives is retained—e.g., where weight is a limiting factor, where other system limits suborn experimentation, where any other factor preclude experiment scheduling. Experiments are eliminated only after less drastic alternatives are considered.

By agreement with NASA, S&ID conducted a preliminary integration of 11 of the 15 AES flight missions. The other four missions were examined only to establish preliminary accommodation and provide interfaces between rendezvous flights.

A different approach was necessary in the integration analysis of the Air Force experiments. These experiments were unspecified as to mission grouping or flight assignment. Insofar as Air Force experiments were concerned, the study objective was to integrate the entire program in a minimum number of launches, with maximum mission accomplishment. A more specific discussion of the approach to integrating Air Force experiments in AES vehicles will be found in the classified supplement to Volume II (Part II). Results of the analysis are included.

SPECIAL NOTE:	Due to a change in the experiment numbering system which occurred midway in this study, instances of incorrect numbering may be encountered. However, every effort has been made to employ new NASA numbers.

APPROACH

The overall experiment integration study logic is shown in Figure 1. The specified experiments were received in a standard NASA descriptive format. Because the degree of definition of individual experiments varied considerably, it became necessary to reduce all experiments to data formats amenable to both technical analysis and computer scheduling. The Critical Interfaces Standard Format was utilized as the uniform tabulation from which equipment requirements and individual subsystems operating profiles were derived. Concurrent technical analyses of data management, controls, displays, and crew operations contributed to the derivation of system design factors which were applied in the computer scheduling analysis.

The product of the study can be called (as noted in Figure 2) "determination of mission feasibility." The value of such a product is based on the level of confidence with which integration can be claimed as feasible, and therefore on the depth of analysis to which available information has been subjected.

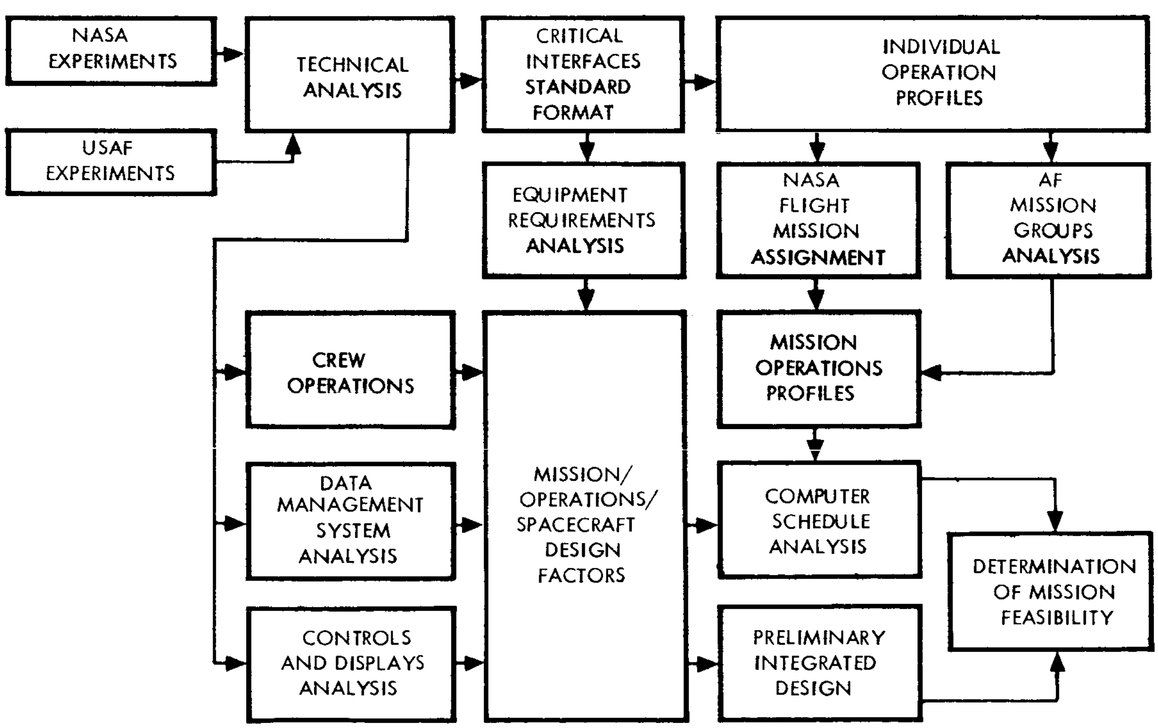

Figure 2. Experiment Integration Logic

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The NASA experiments portion of the study might have included a detailed analysis of the relative capability of various study configurations to accomplish a proportion of the assigned mission. However, because the defined missions tended not to challenge total experimental capacities, relative effectiveness in a purely experimental sense turned out to be either difficult to measure or not applicable. Data to support choices between study configurations, therefore, is generally limited to system and weight comparisons.

STANDARD EXPERIMENT FORMATS

Before the Apollo Extension Systems (AES) experimental flights actually occur, many changes in currently defined experiment parameters may be expected. Existing spacerated equipment will be improved and new equipment will be developed. Manned and unmanned orbital flight programs will precede extended Apollo studies and will affect the basic requirement for scientific observation. The experiments themselves will be subject to increasing scrutiny and continuous redefinition. Under these conditions, the value of current experiment design varies not only with the representativeness of operational demands, but also with the consistency of experiment data applied among various comparison studies. To achieve this consistency and representativeness, a standardized tabulation of critical interface data—based on formats originally furnished by NASA—has been used during this study. The completed formats, in most cases incorporating engineering assumptions necessary to achieve completeness, are contained in Appendixes A and B of Volume II. Data presented in these formats formed the basis for all spacecraft integration analysis.

SUMMARY OF EXPERIMENTAL REQUIREMENTS

Although the experimental requirements contained in standard NASA descriptive formats tend to be limited in definition, they constitute a preliminary data base. At the current stage of system development, such data offer sufficiently detailed mission definition to allow preliminary integration analysis to be undertaken.

Table 2 presents the original basic requirements extracted from experiment definitions; these requirements are summed for each flight mission. The primary source is either the individual NASA descriptive format or the Air Force MOL experiment definition. Where critical data were missing, estimates were made. Also, in those cases where data were obviously in error, corrections were made. Figures in parentheses, used for those cases not integrated by S&ID, indicate that at least a portion of the content may be inaccurate. Weights, volumes and power requirements pertain to equipment operation only and do not include concurrent demands chargeable to the experiments. This fact should be retained when weight or power estimates cited in various sections of the report are compared. Astronaut times are based on limited crew task analyses applied to available experiment procedures. Attitude hold estimates are gross and, because frequencies and operating intervals are not given, can be used only to compare the scope of the requirement between missions. Data return weights and volumes are based solely on experiment format estimates.

Lack of adequate time has prevented a final editing which would ensure a proper footnoting of numbers that changed as the study progressed. Review of the report in detail may uncover examples of different numbers for the same items in different places. In some cases, this may be attributable to arithmetic error. In most such cases, however, the accuracy of the number is a function of the stage to which analysis has progressed. In other words, numbers which appear "deeper" in the document are likely to be more accurate.

COMPOSITE EQUIPMENT LIST

To achieve dimension uniformity for equipment used in various experiments and flight missions, a preliminary composite equipment list was prepared and used as the standard to determine experiment equipment weight and volume. A detailed, common-use equipment analysis has not yet been conducted for the AES series of experimental missions. Pending such analysis, the composite list—presented in Section 2, Volume 2 —will improve the degree of standardization; however, it is not to be considered as complete or definitive.

The next phase of integration will require further development and verification of the composite equipment data applied in this limited study. Air Force equipment specifications, as stated in Air Force experiment formats, were used verbatim.

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Table 2. Summary of Experiment Requirements

	Crew Time (hr)	Equipment Weight (lb)	Equipment Volume (ft^3)	Equipment Power (kw-h)	Attitude Hold (hr)	Weight Data Return	Volume Data Return	Remarks
209	181.3	1653.8	180.3	23.0	9.5	136.0	2.3	
211	341.7	2278.4	23.8	128.4	23.4	296.0	5.4	
507	207.6	4047.4	174.8	59.5	64.0	857.5	17.5	
509	133.8	1899.4	259.7	29.9	44.6	181.7	7.1	
215	180.8	3882.4	121.8	78.4	168.0	843.0	17.2	
513	257.0	1850.4	81.8	29.4	79.7	154.0	2.6	
218	(1071.8)	(2697.4)	(81.6)	(368.9)	(325.3)	(373.0)	(6.1)	Not integrated by S&ID
219	1072.9	1244.1	166.5	375.3	333.0	468.0	7.1	
221	479.8	948.4	27.5	73.1	0.0	333.0	5.5	
516	(1457.5)	(7619.9)	(215.5)	(406.7)	(526.5)	(500.0)	(9.1)	Not integrated by S&ID
518	798.0	8481.4	503.0	478.0	481.6	1256.0	24.3	
521	(646.6)	(2171.4)	(80.5)	(85.9)	(48.0)	(299.0)	(6.0)	Not integrated by S&ID
523	(1513.8)	(6820.4)	(180.6)	(402.7)	(804.3)	(488.0)	(8.5)	Not integrated by S&ID
229	1103.6	2749.1	254.2	375.0	373.9	396.0	6.4	
230	1042.6	2644.1	117.5	370.8	721.5	391.0	6.3	
AF-1	542.0	3722.2	1290.0	413.4	149.0	202.0	2.1	
AF-2	404.5	4038.0	148.3	303.8	75.8	180.0	3.2	

SYSTEM OPERATING PROFILES

The first step in reducing experiment definitions to actual spacecraft operating requirements is the specification of time-sequenced operating profiles for each critical subsystem. During the preliminary integration phase of the current study, the effects of interaction between subsystems themselves could be considered only in the more obvious cases. Advanced integration will require complete analysis of such interactions. The system operating profiles for each experiment are included, when pertinent, in each flight mission section of Volume 2.

Because of the extremely compressed study schedules, the conversion of individual subsystem profiles to a total mission profile was often handled by assuming an average level of subsystem operation, rather than use of a detailed profile. Although this made it possible to expedite completion of the integration analysis, it is also believed to have resulted in generally conservative estimates. This problem is strikingly illustrated by the case of the power subsystem profile of Flight 215. This mission was re-run in the computer scheduling program, using detailed task power profiles on the second run. When so scheduled, a significant decrease in estimated power demand resulted. It is possible that advanced integration studies, undertaken with better experiment definition and incorporating more sophisticated subsystem interactions and detailed profiles, will continue to reflect general decreases in experimental demands.

An example of the complexity of relationships is afforded by the inclusion of G&N system power demand in a detailed task profile. If more than one task should be scheduled by the computer to occur simultaneously, only the G&N power increment for one of the tasks should properly be included. This, in turn, may affect the scheduling, and so on. Practically, it was necessary at this phase of integration methodology to provide manual conversion to mission profiles with resultant inaccuracies as well as higher costs of operation. The next phase of computer development, discussed in the next section, will provide more sophistication and may achieve the degree of advanced integration necessary for determination of system experimental efficiency. It will be noted that the current study is considered to be limited to the third level, preliminary integration analysis, on the scale of integration phases shown in Table 3.

Table 3. Experiment/Spacecraft Integration Phases

Phase	Provides	Useful For
I. Preliminary accommodation analysis	Parametric feasibility	Conceptual planning
II. Advanced accommodation analysis	Operating feasibility within system segments parametric system capacities	Preliminary configuration selection and design
III. Preliminary integration analysis	Operating efficiency within total system under parametric mission cond Gross scheduling of experiment increments within overall system constraints	General system and mission planning
IV. Advanced integration analysis	Operating effectiveness of total system experiment complex Detailed scheduling of system interactions and experiment interfaces Maximum use of total system capacity for each experiment increment	Comparisons between systems
V. Experiment/ system integration	Hardware specs for each experiment flight increment Flight mission operations plans	Flight and production schedule

TIME-SEQUENCED EXPERIMENT SCHEDULES

As mentioned previously, considerable difficulty was encountered in converting each subsystem's experiment operating profiles to a mission profile which accurately reflected task requirements on a time-sequenced basis. Although the logic for mission integration of task profiles is clear, the number of integrations required at each scheduled time interval suggests that the problem cannot be handled without a computer program.

Such a program was used in this study to ensure the feasibility of scheduling each flight mission. The program provides for reasonable allocation of crew time, and it automatically schedules all activities to use subsystem capacities within imposed restraints.

Application of the scheduling program in this study demonstrated the feasibility of scheduling experimental missions for each flight and experiment group under consideration. Minor deviations that resulted from scheduling conflicts are described when they occur in each flight mission section of Volume 2. The complete mission scheduling printout for each flight mission appears in Appendix C, Volume 2 together with a tabulation of rejected experiment tasks.

Almost without exception, the rejection of one or more tasks by the scheduling program resulted from the unavailability of sufficient joint crew time to complete each rejected task within its operational constraints. Superficially, each flight mission appears to be capable of accommodating its assigned experiment group. Indeed, a significant amount of crew time remains unscheduled in every case. The rejected cases therefore constitute an example of the critical importance of computer scheduling as opposed to simple assumption of feasibility based on apparent availability of crew time. Further discussion of this point will be found in the subsequent section on Crew Operations.

DATA MANAGEMENT SYSTEM

A standardized data management subsystem is proposed for use with each of the NASA missions. This system is described in detail in Volume 3. The standardized data subsystem can simultaneously record nine analog continuous channels (frequency response 12.5 to 5000 cps) and one serial PCM-NRZ digital channel (51,200 bps). The recorder speed is 15 inches per second for a period of 30 minutes per reel of magnetic tape.

The analog-to-digital converter, multiplexers and programmer of the standardized data management subsystem can be arranged to process a multiplicity of analog high-level, analog low-level, digital parallel, and digital serial input channels. As an example, the system can digitally process 270 high-level analog channels and 50 low-level analog channels into eight bit words at sampling rates varying from 200 to 1 sample per second. The unit also includes a provision for processing 32 digital parallel inputs at sampling rates of from 200 to 1 samples per second and one 40-bit serial word at 50 samples per second.

In an alternate mode of operation, the standardized system can process and record nine analog continuous channels (frequency response 12.5 to 1250 cps) and one serial PCM-NRZ digital channel (1600 bps). The recorder speed is 3.75 inches per second for a period of 128 minutes. During transmission of this data, the playback tape speed is 120 inches per second when only digital readout is desired; this playback speed permits 120 minutes of recorded data to be transmitted to ground in a period of 3.75 minutes.

Based upon an analysis of the experiment data generated on each mission, the standard system will in general fulfill data management requirements. A summary of such requirements by flight is shown in Table 4. A comparison with transmission capacities (see Communications, Volume 4) indicates difficulty only in the case of Flight 518, which requires 3 hours of transmission time per day. For this flight only, return of data to Earth on tape will probably be required.

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Table 4. Data Management Requirements Summary

Flight	209	211	507	509	215	513	219	221	518	229	230	AF-1	AF-2
Acquistion Type	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Analog and Digital	Digit.	Analog and Digital
Average Acquisition Period (min)	4.9	3.0	8.4	14.0	7.7	14.3	16.4	3.0	10.6	3.0	13.8	33.4	46.5
Total Trans. Time (min)	264.0	562.8	330.3	296.0	420.2	357.3	868.8	840.0	7236.6	840.0	849.4	3074.4	1956.9
Average Trans. Time per Day	18.9	18.8	23.6	21.1	30.0	25.5	19.3	18.7	160.8	18.7	18.9	68.3	43.5

DISPLAYS AND CONTROLS

The technical analysis of each experiment and experiment mission group included analysis of experimental control/display requirements and system constraints. Potential control/display approaches were examined in terms of state of development, availability, adaptability for AES use, user-acceptability, and functional redundancy. A trial control/display configuration was selected for a single typical flight. This configuration was then reviewed for its ability to accomplish the control/display requirements of all other flights, with the aim of achieving standardization between flights and resultant benefits in cost reduction or efficiency.

The conceptual integrated display configuration is shown in Figure 3. The system incorporates a computer and cathode ray tube (CRT). The data processor is used as a display generator for the CRT, and to meet requirements for data storage and retrieval typical of the behavioral experiments series. Dissimilar experiment presentation formats can be modified, along with total data displays, by reprogramming the computer. Computer reprogramming is achieved by a data link either prior to launch or while in orbit. Parallel processors may be used. The system also provides for the potential input of operational subsystems data.

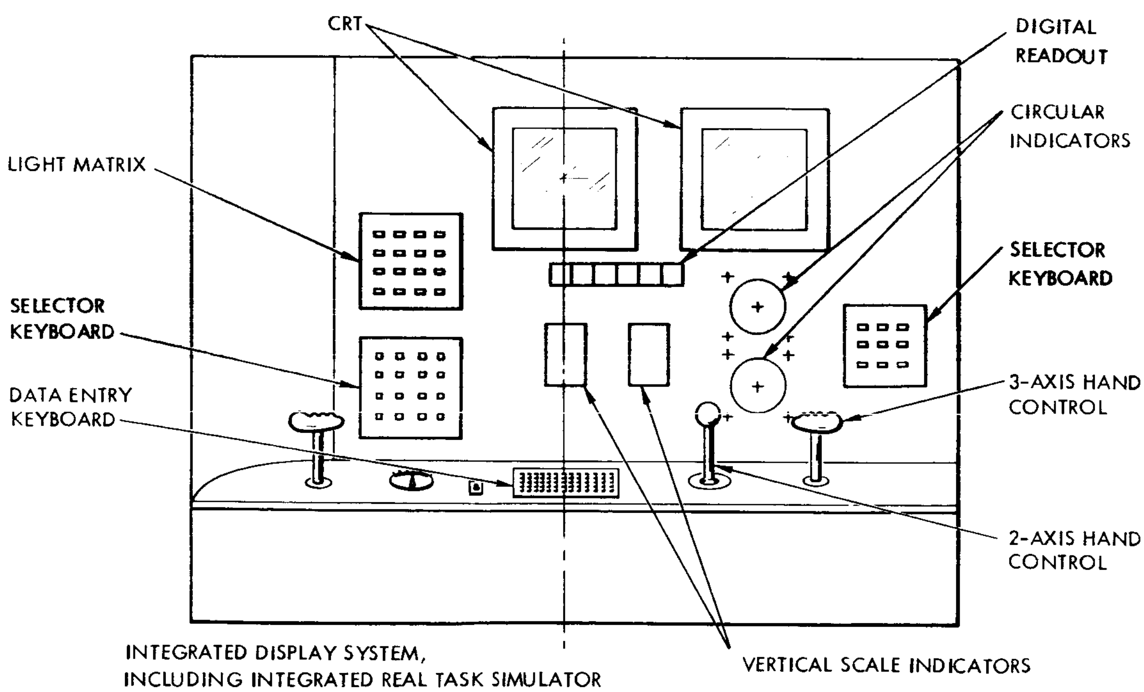

Figure 3. Integrated Display System

CREW OPERATIONS

Crew operations include spacecraft management, crew maintenance functions, and experiment operations, the last-named being of primary interest in the present study

Spacecraft management operations include launch operations, systems management, piloting, inflight maintenance, deorbit and entry, access, and abort. Crew operations during launch are expected to be largely confined to manual backup of certain automatic or ground-controlled system functions. System management operations are those associated with initiation, checkout, monitoring, adjustment, and other routine attention to systems status and action. Piloting functions include attitude control, Delta V, and such navigation operations as may be assigned to on-board crew responsibility. Deorbit and entry are those operations which take place from time of command module/ service module/rack or LEM separation to landing. Access functions refer to general crew movement during the course of spacecraft management, personal maintenance, and (possibly) intervehicular transfer. Inflight maintenance includes such routine adjustment and replacement as may be required or allowed by spacecraft systems and such non-scheduled or emergency repair as may be allowed for the in-the-system design and reliability philosophy. Abort operations include a possible on-board manual backup for launch abort as well as emergency procedures associated with non-scheduled deorbit and entry. These crew operations are described in greater detail in the individual flight mission sections of Volume 2. Crew operations associated with personal maintenance include sleeping, food preparation, eating, exercise, personal hygiene, waste management, and recreation. These are routine crew operations which are common to all flights, except as they may be modified by certain biomedical and human performance experiment requirements.

Although the crew operations associated with the various experiments vary widely in detail from experiment to experiment, it is feasible to describe all of these operations to the individual task level under crew operation categories. This analysis is done for each flight mission in Volume 2. Because the experiments were originally conceived and designed within the context of recognized epistomological areas, each with certain traditional characteristics of research operations, it is feasible to generalize brief crew procedural descriptions for groups of discipline-related experiments:

1. Medicine - This group of experiments is characterized by standard laboratory techniques of provocative testing and biosample analysis and observation. With a few exceptions, the usual procedure

involves experimenter and subject, although the data derived are usually biological and bioelectronic rather than direct observational.

2. Behavior - This group of experiments utilizes standard sensori-psychomotor-intellectual performance tests, most of which can be adapted to one-man performance utilizing a standardized console. The artificial gravity experiments may be considered as special cases of behavioral and medical experiments.

3. Living Organisms - These experiments seem to require technician-type crew operations similar to those of bacteriological or small animal study procedures.

4. Space Environment - These experiments require a wide variety of operations including simple monitoring, operation of ejection devices, sophisticated observation of extravehicular events, and on-board chemical processing of materials.

5. Liquid/Gas and Solids Behavior - These studies tend to require to initiate and control rather complex on-board liquid, gas, and solid processing devices.

6. Astronomical Observations - These experiments generally involve crew utilization of and data gathering from external optics and sensors, both by visual observation and display readout.

7. Remote Sensing of Earth's Atmosphere and Surface - These experiments require crew operations very similar to those required by astronomical observations and utilizing much of the same equipment in much the same way.

8. Electromagnetic Propagation and Transmission - These experiments emphasize communications control and the analysis of resulting displayed data.

9. Space Structures Technology - These experiments involve crew operations in deploying, operating, and observing structures external to the spacecraft. While these operations are usually by remote control and on-board visual observation, some EVA is involved.

10. Subsystem Development and Test - These studies emphasize the observation by the crew of systems operation and of other crew members utilizing on-board operational equipment.

11. Extra-Vehicular Operations - These studies utilize the crew as subjects in various EVA tests.

12. Maneuvering and Docking - These studies utilize the crew as subjects in spacecraft piloting and external observation and control tests.

The crew-time requirements summary (Table 5) includes the following for each flight:

1. The total crew-time required for sleep and for personal maintenance.

2. The total crew-time required for daily scheduled systems management, i.e., management of the operational systems of the spacecraft.

3. The total time required by the experiments.

4. The total unscheduled time remaining after items one through three are deducted from total mission time.

It will be noted that assumptions of flight feasibility can be misleading when based entirely on available hours of crew time. At cursory examination, there would appear to be no reason why crew time should be a limiting factor in any flight shown in Table 5,—with the possible exception of Flights 516 and 523, neither of which was integrated by S&ID. Nevertheless, a number of experiments were rejected due to lack of crew time when flights were subjected to detailed computer scheduling (Appendix C, Volume II).

This apparent paradox occurs whenever either of the following occurs: available crew time is fragmented; crew time is over-scheduled within special experimental constraints, e.g., day-time operations; crew time is available only during times conflicting with spacecraft operations requirements; or when it is not schedulable as joint crew time to the extent necessary to complete an experimental requirement. Only through use of a computer program can assurance of scheduled crew time be obtained.

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Table 5. Crew-Time Requirements Summary

Requirement	209	211	507	509	215	513	218*	219	221	516*	518	512*	523*	229	230	AF-1	AF-2
Flt	209	211	507	509	215	513	218*	219	221	516*	518	512*	523*	229	230	AF-1	AF-2
Days	14	30	14	14	14	14	45	45	45	45	45	45	45	45	45	45	45
Men	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3
Sleep	315	675	315	210	315	315	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013	1013
Personal (incl food)	189	405	189	126	189	189	608	608	608	608	608	608	608	608	608	608	608
Systems mgmt	17	36	17	17	17	17	54	54	54	54	54	54	54	54	54	54	54
Experiments	181	276	193	106	181	181	(1072)	1073	362	(1458)	677	(654)	(1514)	1104	1043	542	404
Unscheduled	306	768	294	213	306	306	(493)	492	1203	(107)	888	(911)	(51)	461	522	1023	1161
Total (man hr/flt)	1008	2160	1008	672	1008	1008	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240

*Not Integrated by NAA. Figures in parentheses are taken from experiment formats without analysis.

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BIOMEDICAL AND BEHAVIORAL EXPERIMENTS

The basic Biomedical/Behavior Experiments Program specified by NASA is included in all AES missions. In actual practice, it is likely that the total basic program will be applied only in the first and, possibly, the second flight of each incremental flight duration. The remaining flights of each duration will most probably be designed on the basis of the results of previous flights. The precise experiments for projected flights cannot be predicted.

In a broad sense, the Biomedical/Behavior Experiment Program (NASA Experiments 0101-0121/0201-0203) is designed to evaluate the effects, over time, of prolonged space flight on man's physiological functioning and performance capability. In general, the biomedical experiments will study a comprehensive cross-section of selected physiological functions. In addition, these experiments will accomplish the following: include measures that will assess the effects of vehicle maneuvers on man; identify the causes of observed degradation; predict the onset and determine the degree of impairment; and, validate selected preventive or counter measures. The behavior experiments will sample a representative cross-section of man's response repertoire; they will also include real operational tasks, simulated crew tasks, and experimental measurement of performance components. The objectives of the overall Biomedical/Behavior Program will most likely be realized by the 21 biomedical and the three behavior experiments. However, from a system engineering point of view, several experiments prove to be excessively costly; the occurrence of some redundancy and confounding of experimental objectives has also been noted.

The fuel requirements for vehicle maneuvers required by the specified design of Experiments 0101 and 0102 often exceed system capability, and at best are costly. The need to evaluate vestibular functioning and crew tolerance of variable rotation rates of zero G is critical. However, it is possible to measure response to linear acceleration and rotation in flight with a modified Barany chair. Although the sensory aspects of acceleration (linear and angular) of a chair within a vehicle are somewhat different than when the vehicle is accelerated and rotated, the differences are probably not gross. In this instance at least, vestibular functioning can be measured in space and compared with ground functioning. Most importantly, on Flight 221 vestibular functioning can be thoroughly studied and effects of zero G with artificial G can be systematically evaluated. Therefore, it is recommended that Experiments 0101 and 0102 be accomplished without special vehicle maneuvering, or that the acceleration and rotation requirements of these experiments be accomplished on only one flight. Where possible, however, the specified maneuvers have been incorporated in flight design.

Experiments 0103, 0104, 0105, 0106, 0107, and 0108 are concerned with evaluation of the cardiovascular system. There is no argument with the need to try a variety of measures to derive the optimum index of cardiovascular functioning. However, the use of the lower body negative pressure device, the exercycle, and other devices for provocative testing, confounds the controls essential for evaluating countermeasures; these devices also confound the results of the provocative tests themselves. In addition, the frequencies for the experiments are different, thus complicating the problem of measurement synthesis. Particularly, the evaluation of countermeasures is contingent upon an acceptable measure of cardiovascular functioning; yet, the frequency of countermeasures is unrelated to the cardiovascular assessment experiments.

Radio-isotope procedures for assessing fluid compartment volumes are costly. Equipment weight for this experiment is 463 pounds. However, biomedical specialists differ as to the best technique for assessing blood volume, total body water, and other fluid compartment volumes with a radio-isotope system. It is very likely that with some changes in the techniques or radio-isotopes used, other equipment could be utilized which would greatly reduce the 463-pound equipment requirement. Insofar as behavior experiments are concerned, the sensitivity and feasibility of the following measures are questionable: Experiment 0201-e-Orientation, position and location; Experiment 0202-a-Locomotion; and Experiment 0203-a-Dexterity (don and doff spacesuit).

PRESSURIZED VOLUME REQUIREMENTS FOR EXPERIMENTAL OPERATIONS

For the AES series of flights under consideration, the minimum pressurized volume requirement is established by the biomedical and behavioral experimental program common to all flights. The estimated volume minimum for this program is about 200 cubic feet. This volume also fulfills minimum requirements for other experiments, including the Air Force series.

It is emphasized that this is not presented as an optimal volume nor necessarily habitable for long durations; rather, it is presented as an adequate volume within which a specified set of operations can be accomplished.

Among the factors considered were the following: layout of standardized controls and displays, packaged equipment dimensions storage area, accessibility of the data management system panel, adequate work bench space, location of necessary hatches and ports, and structural configuration constraints. To these basic constraints can be added the operating volume required for two crewmen, (acting as observer and subject, respectively) to accomplish minimum movements demanded by the experimental design. Experimental procedures require capability for face-to-face and/or side-to-side relationships, both sitting and standing. It will be seen from Figure 4 that the specified volume of approximately 200 cubic feet is minimally adequate and can be used as the basis for sizing the rack airlock. Usable volume of this size cannot be provided within the three-man command module.

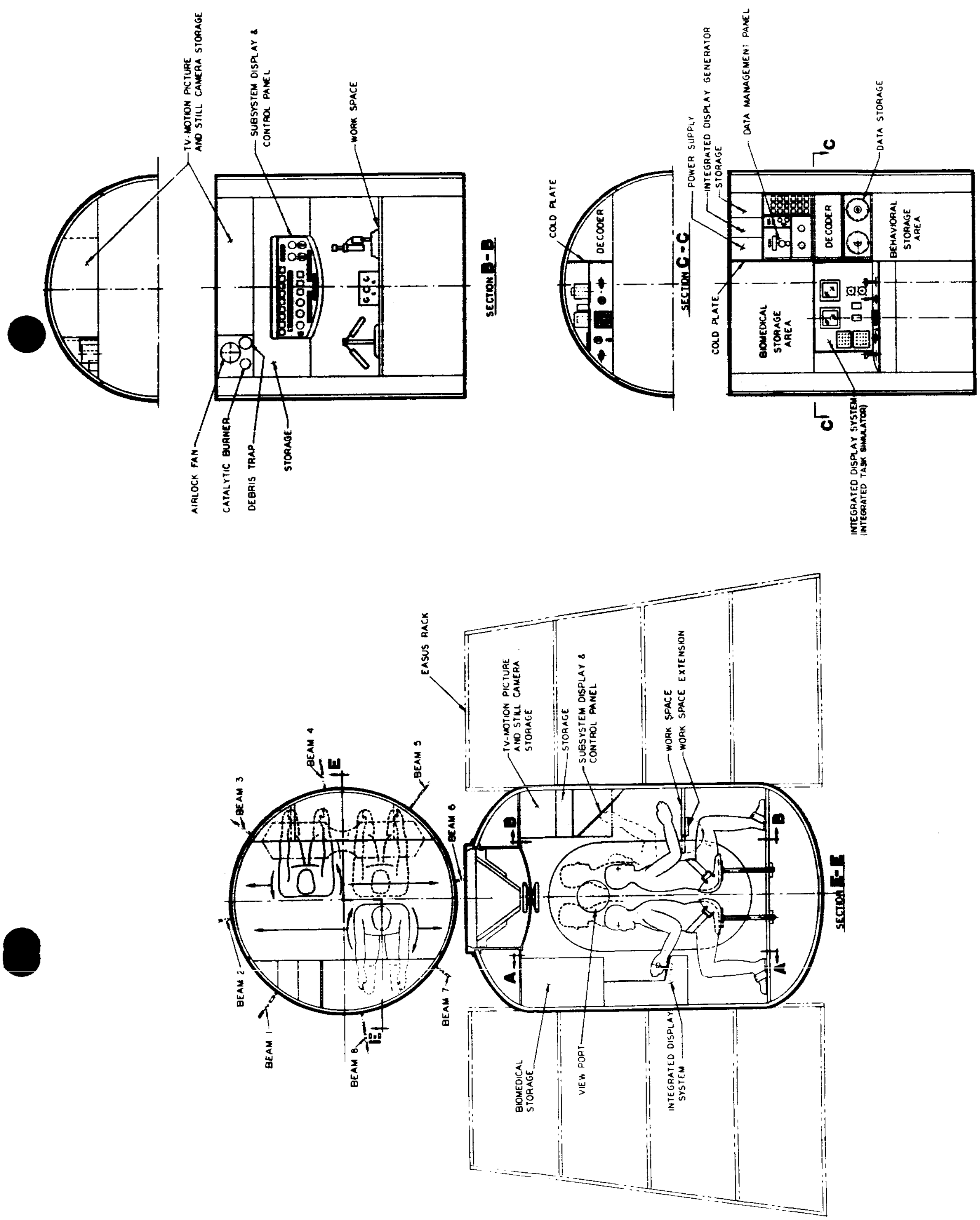

Figure 4. Pressurized Volume Requirements

INTEGRATION OF AIR FORCE EXPERIMENTS

The approach to integration of Air Force experiments in the study configurations has been necessarily different than the approach to integration of defined NASA experiments with specified flight missions. The desire to optimize Air Force experiment groupings by accomplishing the total program in a minimum number of launches implies a more advanced integration study, requiring considerable iterative analysis.

An iterative analysis could not be carried to completion during the abbreviated time span of this study, and it will be seen that the preliminary Air Force flight groupings, when submitted to computer analysis, could not be completely scheduled.

The accommodation of AF-1 and AF-2 on two 45-day Apollo configurations with experimental racks has been fully demonstrated. The integration in terms of adequate scheduling of systems and crewmen is demonstrated in part, but a number of tasks and one whole experiment have at this stage been rejected due to lack of sufficient joint crew time, or due to conflicts in crew scheduling. This occurs in spite of the fact that utilization of crew time is at only about 2/3 of that available. Since the problem is one of scheduling, it is reasonable to suggest that further iteration will provide assurance of Air Force experiment integration. For the moment, the conclusion must remain that advanced accommodation has been demonstrated, but that preliminary integration is as yet incomplete.

SUMMARY OF INTEGRATION ANALYSIS

Table 6 presents the salient points concerning the potential integration problems in each flight mission. In one sense, the tabulation constitutes a statement of study conclusions. However, as has been pointed out, iteration of results has not been possible. Except in the case of the Air Force Flights, for example, no attempt to reschedule missions at reduced durations has been made. Black-bordered blocks in Table 6 represent critical areas which prevent the meeting of mission objectives. Blocks with shaded edges indicate problem areas that require modification of experiment frequency or flight duration, but do not necessarily prevent meeting of mission objectives. Interpretation of data contained in the table should be qualified by details included in the main text of the report.

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Flt. No.	Plan. Dur. (Days)	Orbit		Gross Weight Req'd	Payload Avail.	Net Weight Margin	Rev. Weight Req'd	Rev. Weight Margin	RCS Capacity Exceeded	Reduce RCS/SPS Exps.
		Incl.	Alt.							
209	14	28.5	200	29,056	32,670	+3,614	-	-	No	No
211-D	30	28.5	200	33,609	32,670	-939	32,206	+461	Yes	Yes
507	14	90.0	200	32,114	106,495	+74,381	-	-	Yes	Yes
509	14	EQ	SYN	43,104	57,250	+14,146	-	-	Yes	Yes
215	14	50	200	33,165	30,158	-3,007	29,917	+241	Yes	Yes
513	14	81.5	200/700	38,551	106,495	+67,944	-	-	Yes	Yes
218-C	45	28.5	200	32,386	32,670	+284	-	-	*	*
218-D	45	28.5	200	35,716	32,670	-3,046	*	*	*	*
219-C	45	28.5	200	32,629	32,670	+41	-	-	Yes	Yes
219-D	45	28.5	200	34,559	32,670	-1,889	32,579	+91	Yes	Yes
221-C	45	28.5	200	30,333	32,670	+2,337	-	-	No	-
221-D	45	28.5	200	33,663	32,670	-993	32,670	0	No	-
516-C	45	EQ	SYN	54,061	57,250	3,189	-	-	*	*
516-D	45	EQ	SYN	56,006	57,250	+1,244	-	-	*	*
518-C	45	83 Ret	200	43,873	106,495	+62,622	-	-	Yes	Yes
518-D	45	83 Ret	200	50,137	106,495	+56,358	-	-	Yes	Yes
521-C	45	EQ	SYN	47,470	57,250	+9,780	-	-	*	*
521-D	45	EQ	SYN	49,415	57,250	+7,835	-	-	*	*
523-C	45	28.5	200	37,329	219,250	+181,921	-	-	*	*
523-D	45	28.5	200	40,574	219,250	+178,676	-	-	*	*
229-C	45	28.5	200	33,135	32,670	-465	32,640	+30	Yes	Yes
229-D	45	28.5	200	36,465	32,670	-3,795	32,670	0	Yes	Yes
230-C	45	28.5	200	32,995	32,670	-325	32,599	+71	Yes	Yes
230-D	45	28.5	200	36,325	32,670	-3,655	32,530	+140	Yes	Yes
AF-1C	45	28.5	200	34,420	32,670	-1,750	32,605	+65	No	No
AF-1D	45	28.5	200	37,992	32,670	-5,322	32,547	+123	No	No
AF-1C Revised	34	28.5	200	32,605	32,670	+65	-	-	No	No
AF-2C	45	28.5	200	34,265	32,670	-1,595	32,615	+55	No	No
AF-2D	45	28.5	200	37,837	32,670	-5,167	32,557	+113	No	No
AF-2C Revised	35	28.5	200	32,615	32,670	+55	-	-	No	No
AF-3, AF-4	45	28.5	200	-	-	-	-	-	-	-

(shaded) Correctible by change in experiment frequency or flight duration.

*Not integrated by S&ID—data not available

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Table 6. Sur

EPS Capacity Exceeded	Daily Comms. Minutes Avail.	Daily Comms. Minutes Req'd	Avail. Total Crew Time (Hrs.)	% Crew Time Used C-1	% Crew Time Used C-2	% Crew Time Used C-3	% Avg. Crew Util.	Total Exp. Tasks at Plan Dur. Req'd	Total Exp. Tasks at Plan Dur. Sched.	% Prog. Compl. (Plan Dur.)	Rev. Dur. (Days)	
Yes	240	18.9	1,008	70	66	72	69	580	579	99.9	12.3	Add batteries to 14
No	240	18.8	2,160	66	65	71	67	1,239	1,239	100.0	-	
Yes	60	23.6	1,008	74	70	70	71	670	669	99.9	12.8	Add batteries to 14
Yes	Cont	21.1	672	71	67	-	69	444	439	98.9	13.5	Two-man only. Ac
Yes	174	30.0	1,008	68	71	78	72	719	717	99.7	11.3	Low inclination orbi
Yes	66	25.5	1,008	78	74	81	78	753	750	99.6	11.9	Add batteries to 14
*	240	*	3,240	*	*	*	*	*	*	*	-	
*	240	*	3,240	*	*	*	*	*	*	*	-	
No	240	19.3	3,240	65	64	69	66	1,649	1,648	99.9	-	
No	240	19.3	3,240	65	64	69	66	1,649	1,648	?	33.0	Reduced duration to
No	240	18.7	3,240	66	63	68	66	1,790	1,790	100.0	-	
No	240	18.7	3,240	66	63	68	66	1,790	1,790	?	39.0	Reduced duration to
*	Cont	*	3,240	*	*	*	*	*	*	*	-	
*	Cont	*	3,240	*	*	*	*	*	*	*	-	
No	66	160.8	3,240	75	71	80	75	2,619	2,577	98.4	-	Uprated RCS require
No	66	160.8	3,240	75	71	80	75	2,619	2,577	98.4	-	Uprated RCS require
*	Cont	*	3,240	*	*	*	*	*	*	*	-	
*	Cont	*	3,240	*	*	*	*	*	*	*	-	
*	240	*	3,240	*	*	*	*	*	*	*	-	
*	240	*	3,240	*	*	*	*	*	*	*	-	
No	240	18.7	3,240	83	76	82	80	2,810	2,756	98.1	-	
No	240	18.7	3,240	83	76	82	80	2,810	2,756	?	22	Reduced duration to
No	240	18.9	3,240	80	74	80	78	2,634	2,519	95.6	-	
No	240	18.9	3,240	80	74	80	78	2,634	2,519	?	22	Reduced duration to
No	96	68.3	3,240	68	68	72	69	2,528	2,462	97.4	34	See AF-1C revised
No	96	68.3	3,240	68	68	72	69	2,528	2,462	97.4	12	Reduced duration to
No	96	68.3	2,448	72	70	75	72	2,018	2,008	99.5	-	
No	96	43.5	3,240	63	61	64	63	2,137	2,035	95.2	35	See AF-2C revised
No	96	43.5	3,240	63	61	64	63	2,137	2,035	95.2	13	Reduced duration to
No	96	43.5	2,520	65	63	67	65	1,746	1,744	99.9	-	
-	96	-	3,240	-	-	-		-	-	-	-	Insufficient definiti

Experiment objective cannot be met.

2

nmary of Integration Analysis

Remarks
days.
days.
d batteries to 14 days.
t allows 13.3 days. Artificial g experiment objective not met.
days.
save weight.
save weight.
:d.
:d.
save weight. Experiment schedule unknown.
save [illegible]ght. Experiment schedule unknown.
or re-schedule at reduced duration.
save weight. Important experiment objective cannot be met.
or re-schedule at reduced duration.
save weight. Important experiment objective cannot be met.
n to allow integration.

CONFIGURATIONS AND EXPERIMENTS ACCOMMODATION

This portion of the study was concerned with the analyses of spacecraft configurations designed to accommodate NASA specified experimental packages with NASA specified mission constraints. All configuration concepts were modifications to the Block II CSM which resulted, to various degrees, in configurations capable of accommodating the experimental requirements for mission durations up to 45 days and are described in Volume 3.

A rack with a central airlock is housed in the spacecraft LEM adapter (SLA) during boost, and was designed as the primary vehicle component in which to install experiments. An alternative location for experiments that require no access by the astronauts is available on a pallet in Sector 1 of the service module (SM) for all configurations but those utilizing this sector for cryogenics and fuel cells. The pallet had been previously designed by NAA under Contract NAS9-3923 and reported in NAA Report No. SID 65-266.

Time did not permit the detailed design of a rack that was optimum as to weight, size, cost, and manufacturing complexity. The size of the rack was set by the necessity of spanning the four LEM attach points in the spacecraft LEM adapter and providing as much volume as possible above the LEM attach points for installation of subsystems and experiments that had not yet been completely defined. Eight beams were provided for attachment of major equipment and from which to span shelves for the small equipment. The airlock was sized by preliminary definition of experimental pressurized volume requirements.

Experiment packages, as defined by NASA at the start of the program and modified by concurrent experimental studies, were integrated into the rack for each flight and each configuration. No attempt was made to define the experiments to a greater extent than that required from a packaging standpoint. The ultimate purpose of the study was to demonstrate packaging concepts and mission feasibility.

For each flight and each configuration, layouts were made indicating the general mission and spacecraft components with a table listing experiments required for that flight. Mission-oriented layouts of rack internal arrangements, CSM, and experiments as required from a packaging viewpoint are presented in Volume 3.

COMMAND MODULE (CM) MODIFICATIONS

Only minor structural rearrangements to the Block II Apollo are required to make the CM compatible with all study configurations.

For all flights, the CO_2 absorbers and food have been removed to the rack with the exception of a one-day supply. All Block II scientific equipment has been deleted. This has been accomplished to maximize the storage volume availability for return of orbit data and AES scientific equipment. For flights in excess of 14 days, other crew systems such as medical and hygienic supplies have also been stored in the rack instead of the CM. Slight modifications to the internal arrangement, particularly the lower equipment bay, are required to accommodate the extended-life subsystems for Configurations C, D', and D.

Minor changes to the electrical power system have been made. Two electrical umbilicals are added for the ac power supply to the rack, and are stored in the aft bulkhead with the Apollo Block II umbilicals. The power lines are installed similar to the regular dc power lines of the Apollo Block II. They are connected into the electrical power system in the righthand equipment bay and attached to a junction connector in the command module forward bulkhead. The umbilicals are plugged in at this point and run to the rack junction connector, which is installed in the wall of the rack hatch tunnel.

The communication system has been rewired to provide communication between the rack and CM. A blower and flexible removable duct are provided in the righthand forward equipment bay for the environmental control system to maintain air circulation between the CM and the airlock. For configurations D and D', a 3/8-inch diameter flexible air line is added to carry 100 psi O_2 from the rack to the CM. This umbilical is stored on the aft bulkhead.

To provide for Flight 509, which includes capture and return of Syncom III, the seat and leg pans of the center couch are removed to allow stowage of Syncom III on the aft bulkhead against the lower equipment bay.

SERVICE MODULE (SM) MODIFICATIONS

The service module is a cylindrical structure connected to the aft end of the command module, providing the propulsion capability, electrical power, reaction control, and the major portion of the environmental control system in the form of subsystem consumables.

For purposes of this study, the SM arrangement for Configurations 1 and D' are identical to the Block II Apollo SM. Sector I is empty of equipment and has hard points built into the basic structure for mounting the lunar mapping and survey equipment or an experiments pallet. Sectors II, III, V, and VI contain tankage for 41,000 pounds of SPS propellant. On the covers for these sectors are installed four interchangeable modular RCS packages consisting of a four-nozzle cluster and one each of oxidizer, fuel, and helium pressurant tanks. Sector IV contains three 400-hour fuel cells and two each of cryogenic O_2 and H_2 tanks.

The center section houses large spherical helium pressurant tanks for the SPS, and serves as a structural support for the main propulsion engine, which is attached to, and extends below, the aft bulkhead.

Configuration D is defined as being identical to the above described configurations, except that a change to the RCS tankage is allowed if more RCS propellants are required by the mission. The modification consists of replacing the one set of Block II RCS tankage with two sets of LEM RCS tankage for each RCS nozzle cluster. To accomplish this, new but interchangeable sector covers for Sectors II, III, V, and VI will be required. During the study, experiment requirements dictated that all NASA missions include the maximum RCS tankage.

The SM for configuration C is basically that developed for the Apollo X, which nominally provides for a 45-day mission duration. Additionally, electrical power capacity has been provided by replacing the three 400-hour Block II fuel cells with four 1000-hour fuel cells (three in Sector IV and one in Sector I) and by increasing the size of the EPS and ECS cryogenic consumable tanks in Sector IV. An identical pair of these cryogenic tanks are also added to Sector I. Additional RCS capacity is again available by utilizing the two sets of LEM RCS propellant tanks for each RCS nozzle cluster in place of the one set of Apollo-type tanks. For low earth orbital inclination mission modes, only a small amount of SPS propellants is required. For these missions, the propellants can be contained in four spherical tanks, one each in Sectors II, III, V, and VI, of the same diameter as the nominal Block II tanks. The reduced propellant quantity also permits removal of one of the two spherical helium pressurant tanks. These modifications result in a weight saving of approximately 1100 pounds.

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RACK DESCRIPTION

The geometry of the experiment rack is that of a cone frustrum having a 178-inch diameter at the top and a 215-inch diameter at the base. It is 118 inches high. A 72-inch diameter cylindrical airlock at the center of the rack is supported by eight radial beams spaced at 45-degree intervals connecting the airlock and the rack outer shell. The upper and lower bulkheads are mounted on the outer shell. The pressurized volume of the airlock is 216 cubic feet, and unpressurized volume of the rack is 1740 cubic feet. The rack is shown in Figure 5.

AIRLOCK

The airlock is a cylindrical 72 inches in diameter by 118 inches long. In order to achieve modular growth potential, the airlock was designed with a universal-type pressure frame to each end. The frames have identical inner bolting flanges that can be mated with a pressure dome containing either a docking drogue or docking probe, depending upon the mission. Rack/CSM docking mechanics are identical to those of the Apollo, since the docking drogue and probe are the same. A metal gasket or O-ring is used between the bolting flanges for pressure tightness (View D of Figure 5). When a single rack is required, the aft end of the airlock is closed out with an elliptical dome. If a larger volume is required to accommodate additional experiments or subsystems, a second rack may be added before launch in a base-to-base tandem arrangement within the LEM adapter. This is accomplished simply by removing the four support fittings from the second rack and removing the aft domes of both airlocks before bolting the two racks together at the outer and inner frames. Between the bolting flanges of the inner frames, a metal gasket or O-ring is used to seal the joined airlocks. At the other end of the airlock of the second rack, the appropriate airlock closure configuration may be installed. The airlock cylinder and skirts are made of integral skin-stringer panels joined by welding. two door hatches are provided on opposite sides of the airlock for access to the experiments compartment. Aluminum material is used for structural members throughout.

NONPRESSURIZED COMPARTMENTS

The experiments compartment is divided into eight equal sectors by radial beams. The radial beams, which carry all the loads from the airlock to the outer skin, are of the milled web-stiffener type. Passageways are provided in beams 1, 2, 5, and 6 for crew access to the experiments. The

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[redacted]

forward and aft ends of the sectors are closed by sandwich bulkheads riveted to the radial beams (B-B of Figure 5). Each sector is provided with shelves for mounting a variety of experiment packages. The shelves are removable to permit installation of variable-sized experimental equipment or subsystems in any sector. The rack is covered by eight skin-stringer panels. A meteoroid bumper is incorporated into the panels by bonding one inch of polyurethane foam layer to the skin and covering it with a bonded aluminum foil facing sheet (C-C of Figure 5). The sector covers are constant in size and are fastened with screws to allow their removal for accessibility to the experiments. They are designed for jettisoning by simply adding the prime-cord separation device and protective shield along the four sides of the sector cover (J-J, K-K, L-L, and M-M of Figure 5). The jettisonable and non-jettisonable sector covers are interchangeable. Some sector covers incorporate the EPS and ECS radiators by replacing the aluminum facing sheet with the radiator panels (new C-C of Figure 5). In View N-N of Figure 5, tie rods are shown in place of the sector cover as an alternate structure for open bays. All structural members are aluminum.

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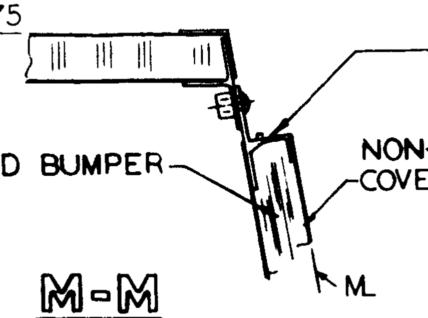
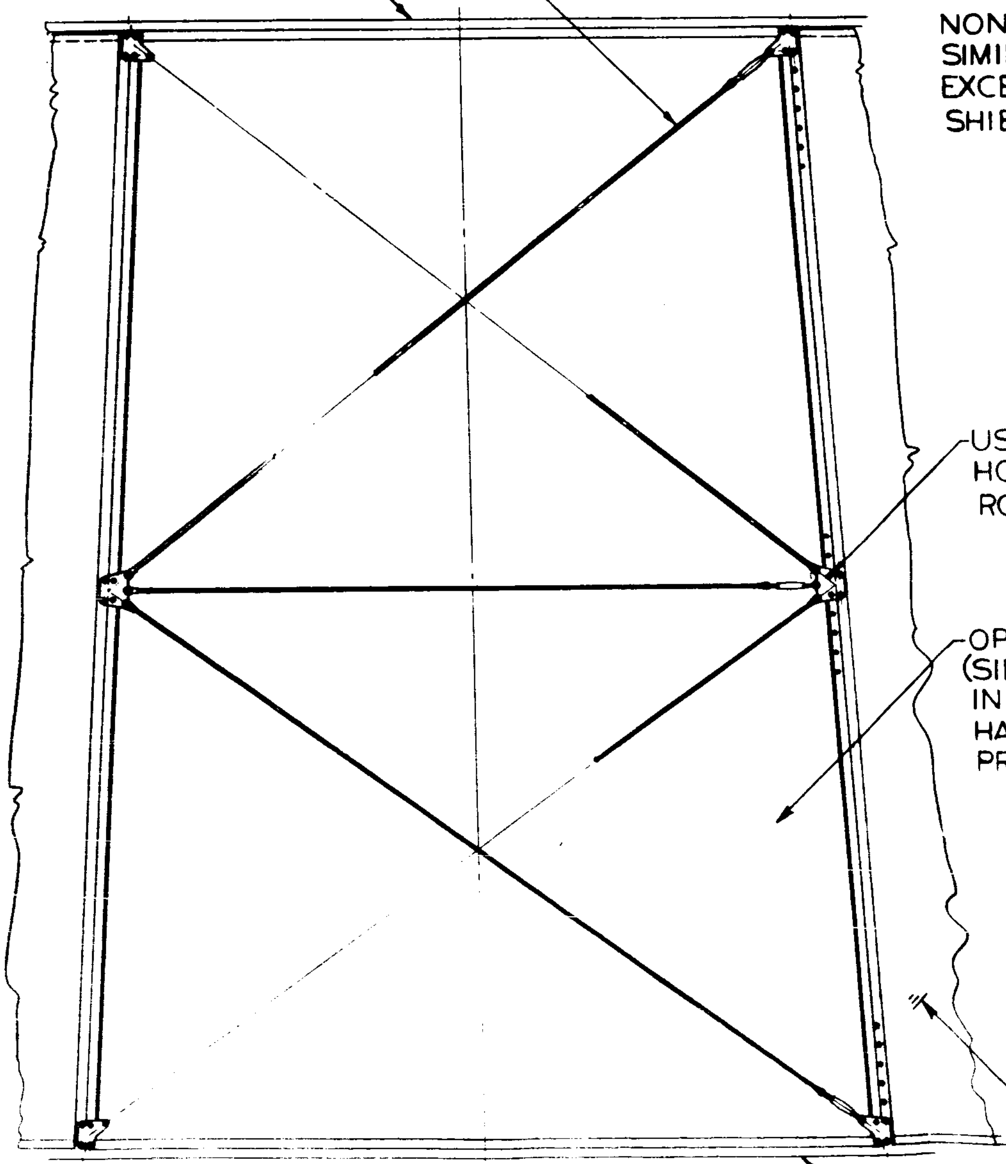
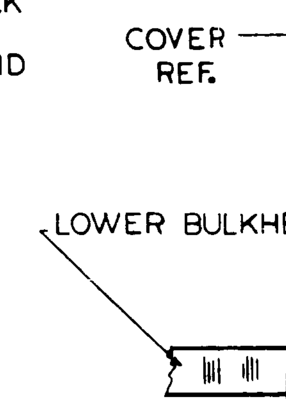


M-M

NON-JETTISONABLE COVER IS SIMILAR TO JETTISONABLE COVER EXCEPT SEPARATION DEVICE AND SHIELD ARE REMOVED

1/2 SIZE



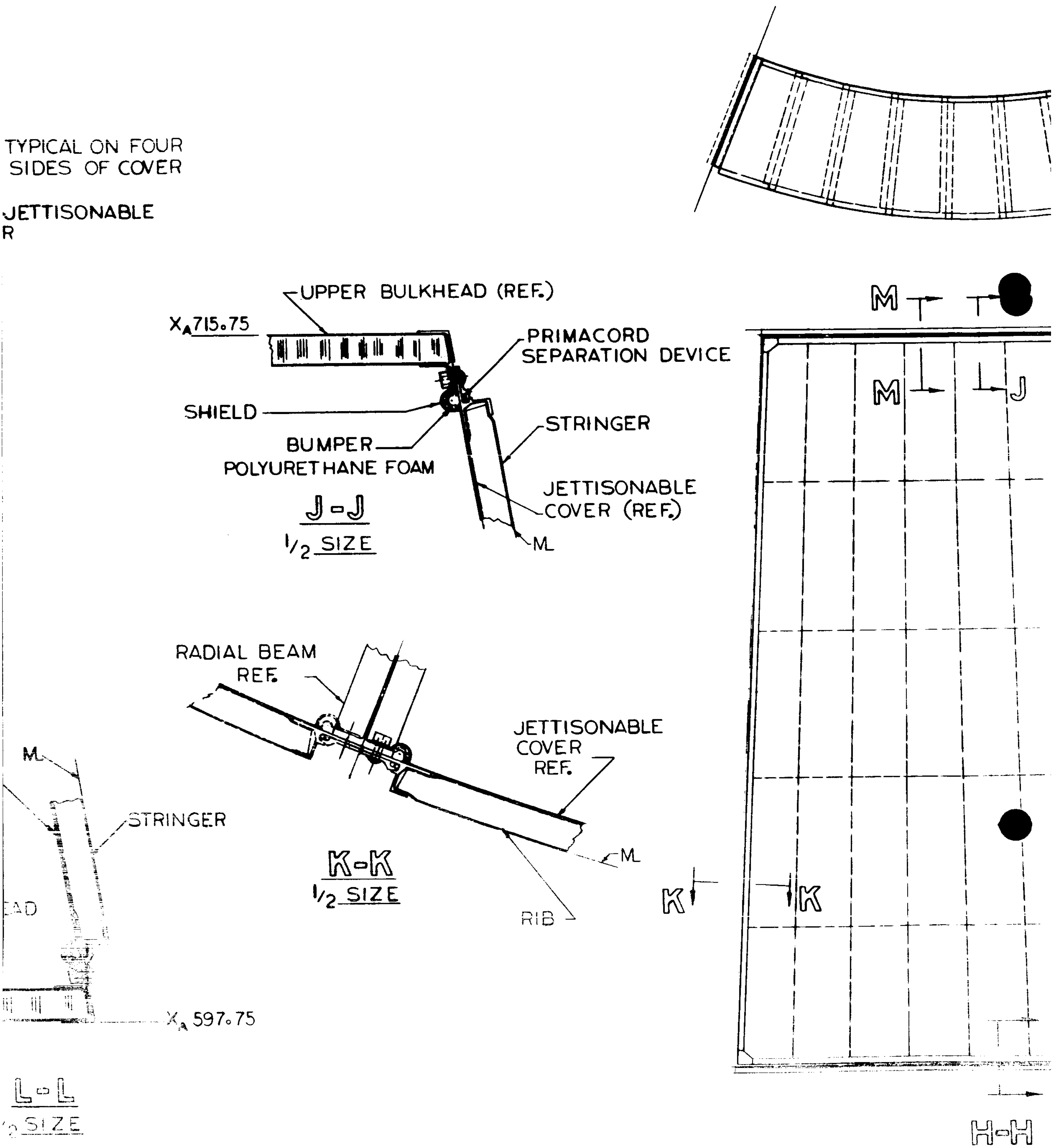


N-N (ROTATED 67.5°)

ALTERNATE OPEN BAY STRUCTURE — SECTOR COVER REPLACED BY TIE RODS

1/10 SIZE

1



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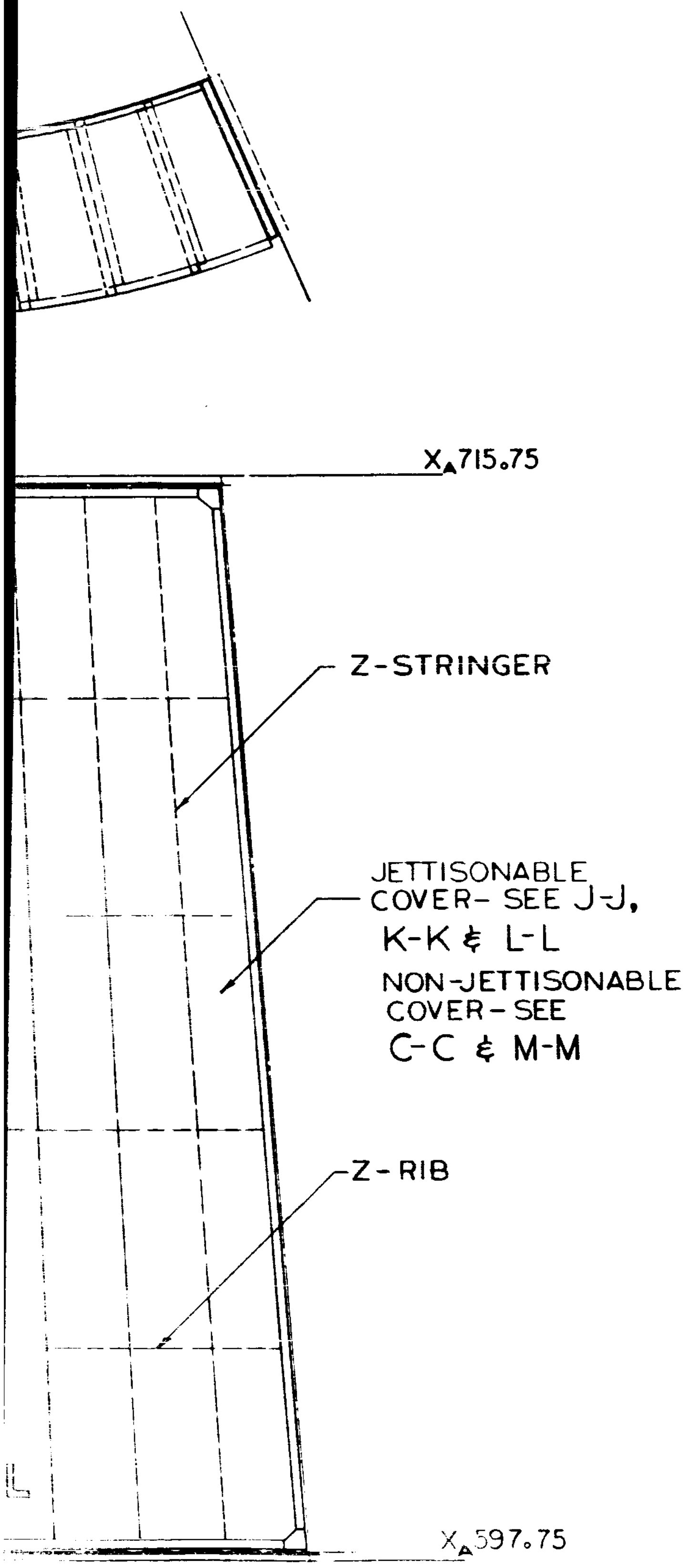
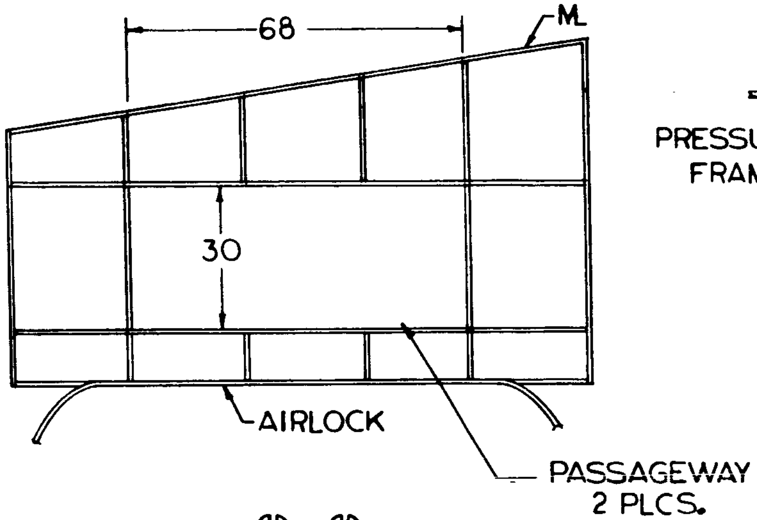
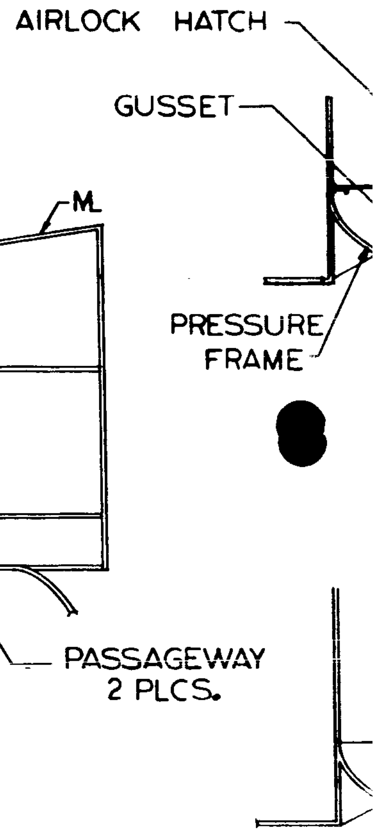
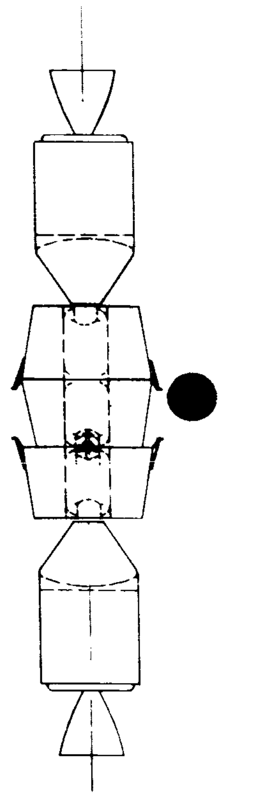


ATED (22.5°)
OVER







ORBITAL CONFIG. 3

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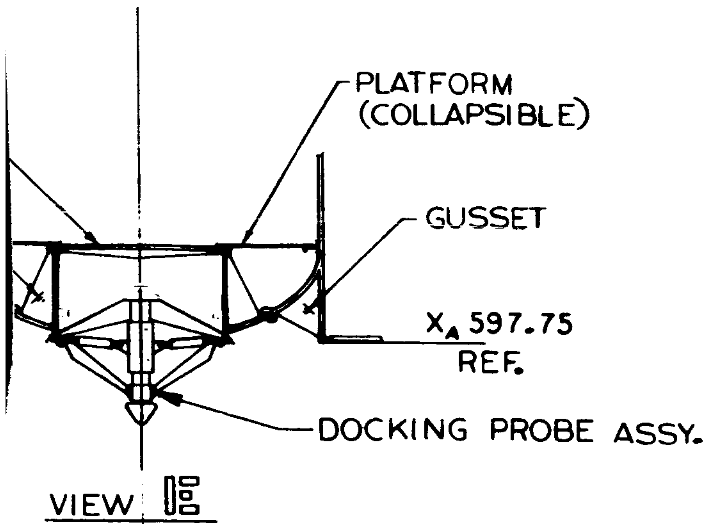

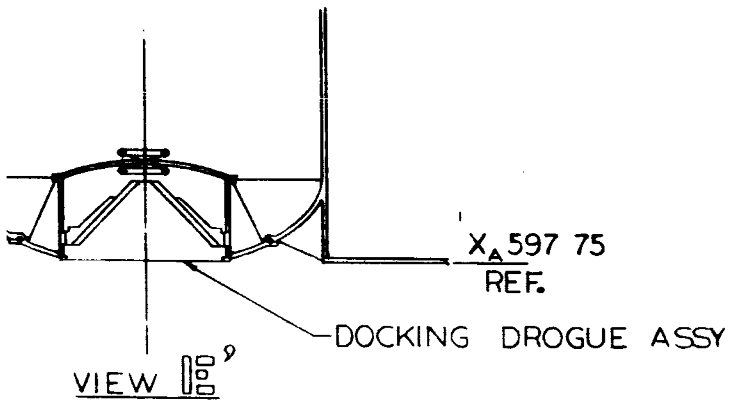

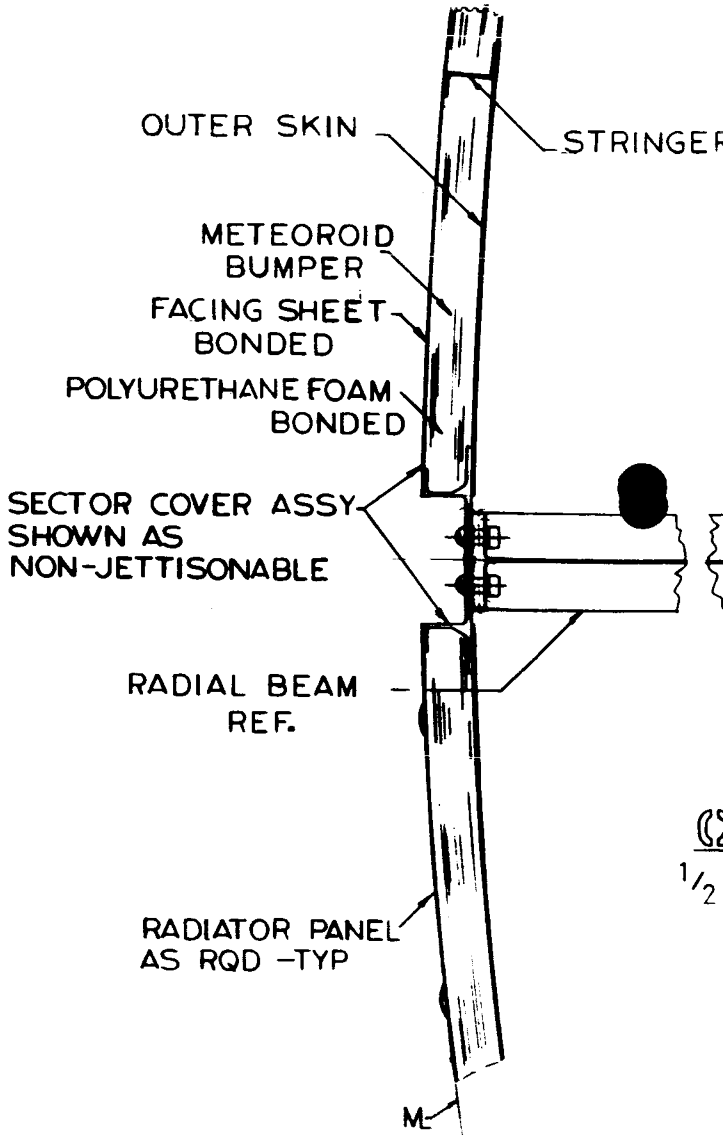

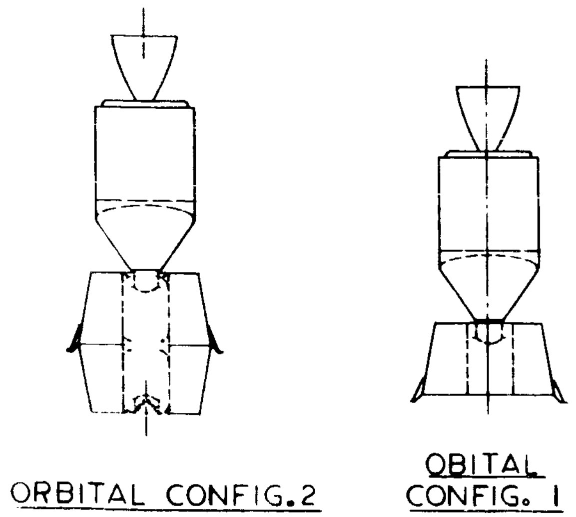

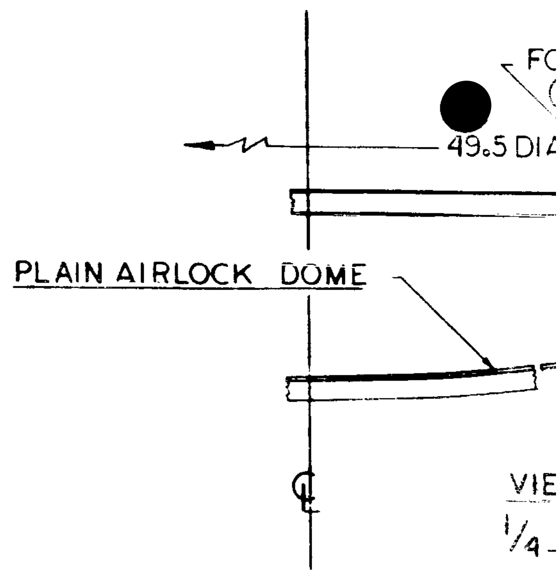

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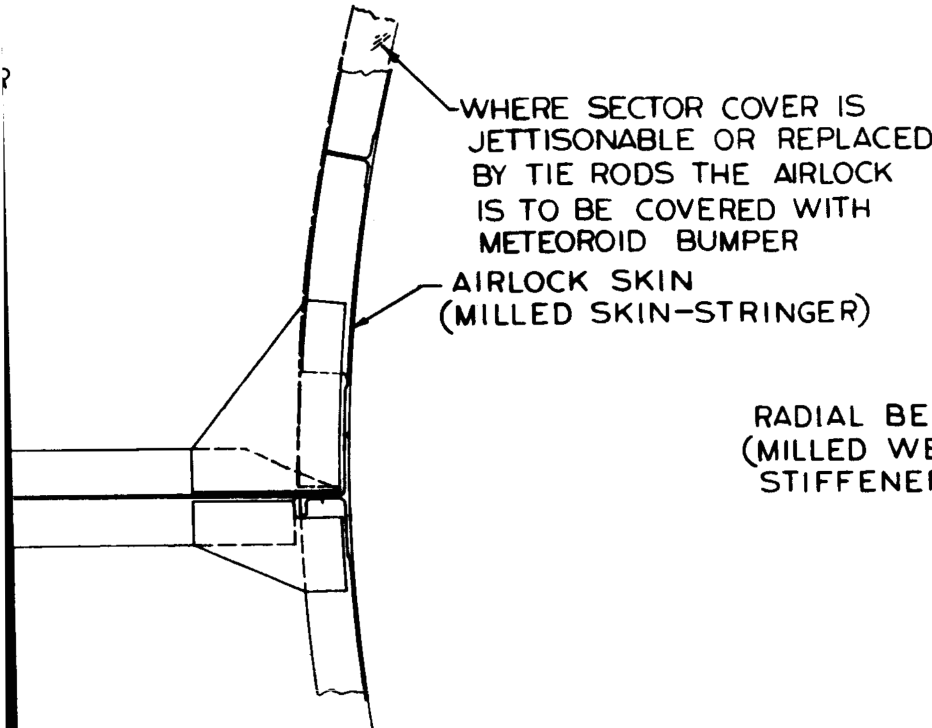
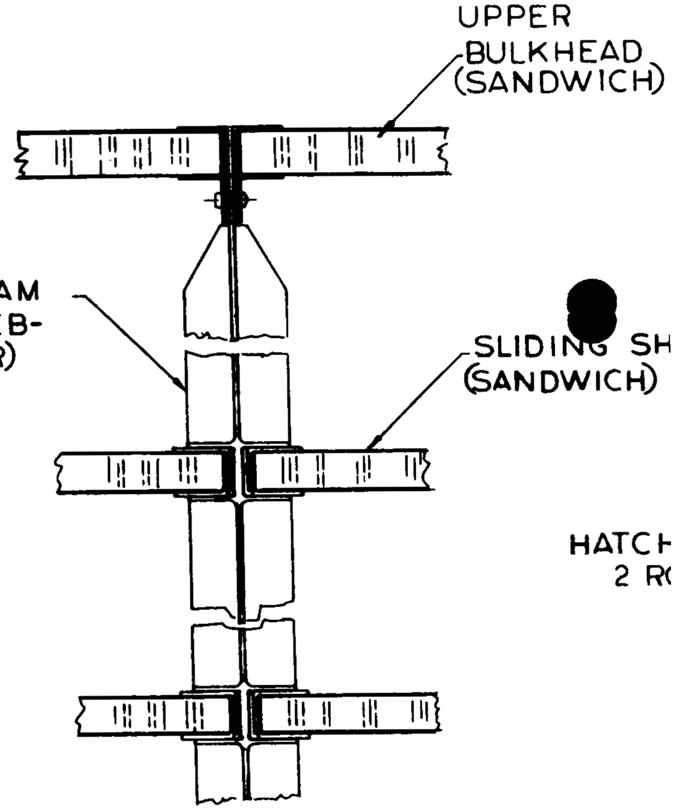
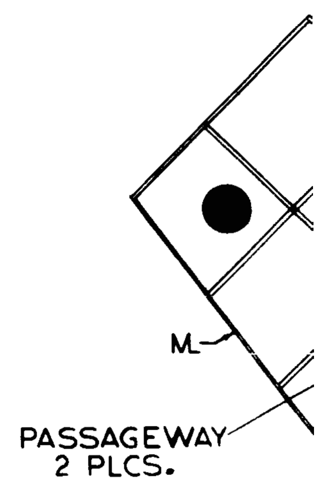
4

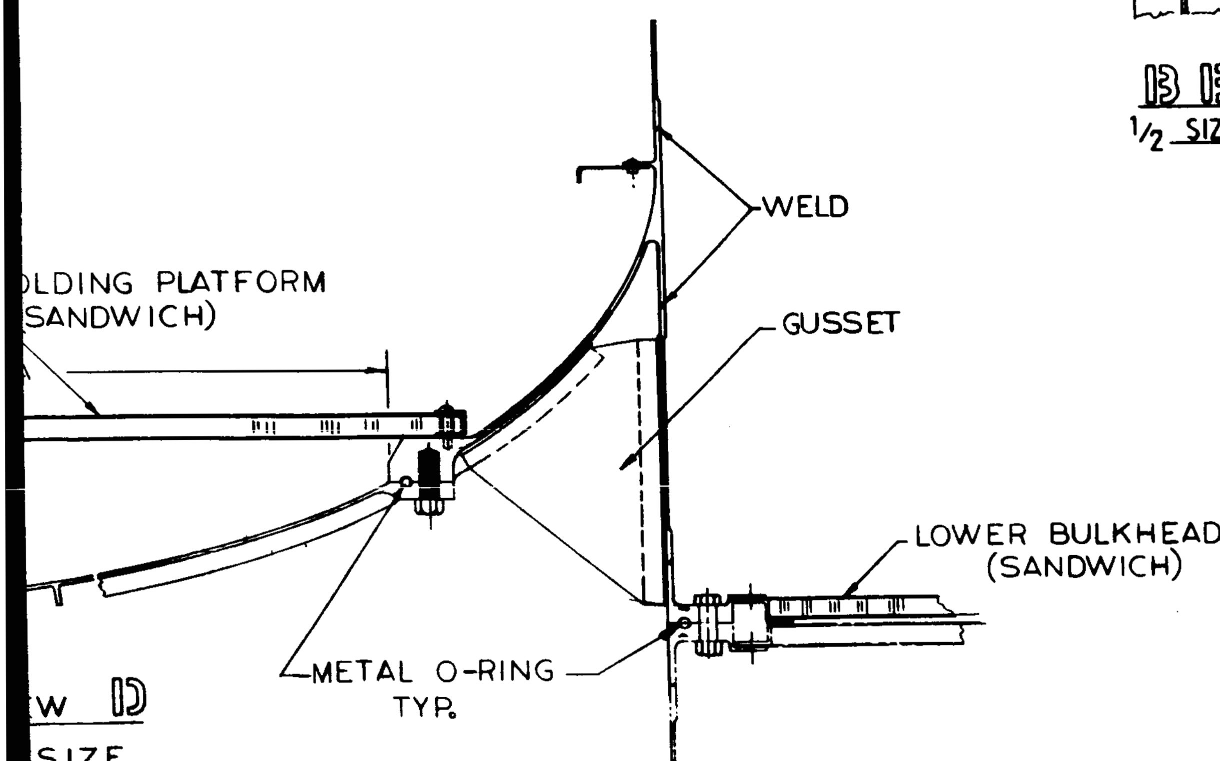


C-C
SIZE



B B
1/2 SIZE





W D
SIZE

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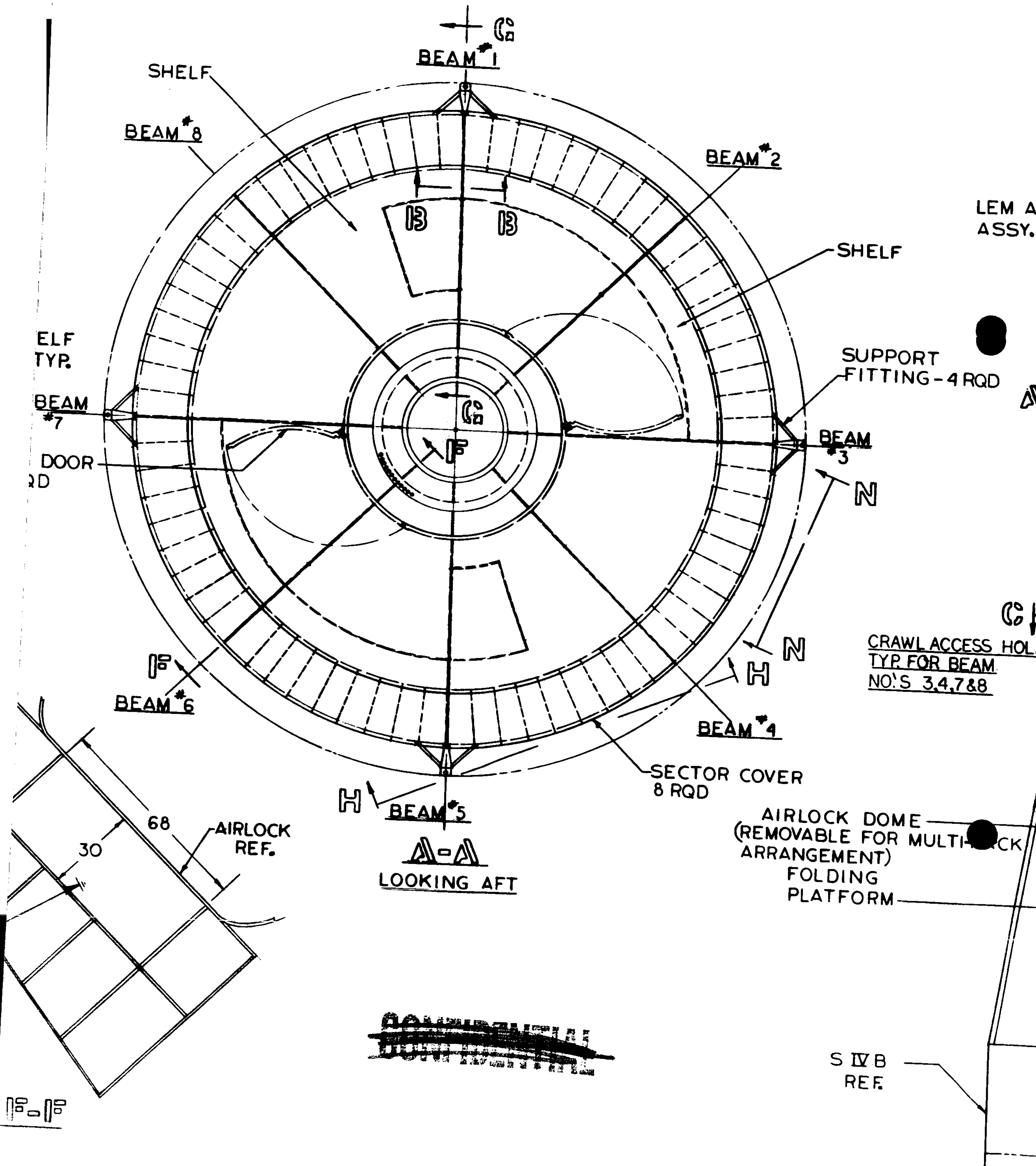
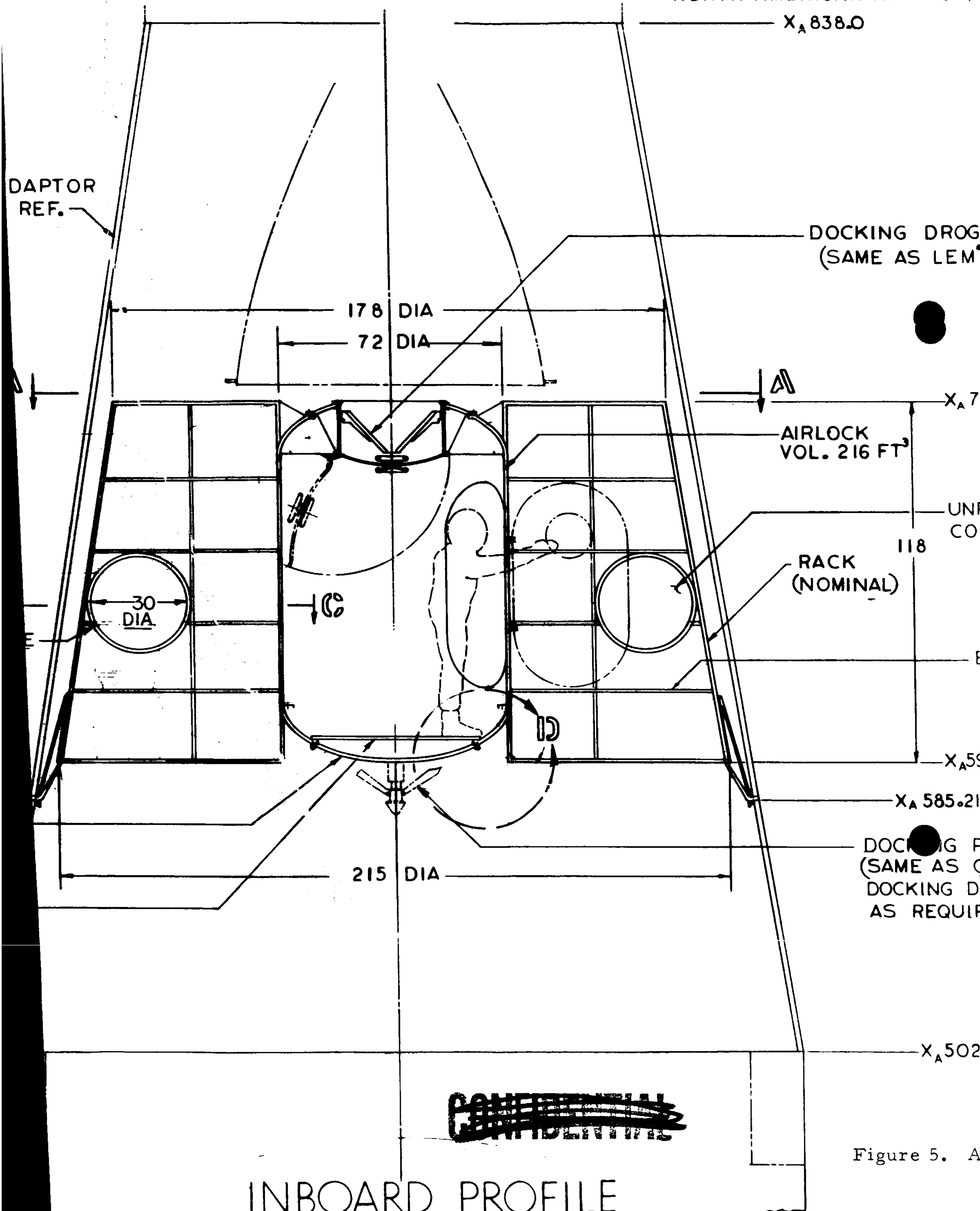


A-A
LOOKING AFT



X_A 838.0
DAPTOR
REF.
DOCKING DROG
(SAME AS LEM
178 DIA
72 DIA
A
X_A 7
AIRLOCK
VOL. 216 FT^3
UN
CO
118
RACK
(NOMINAL)
30
DIA
C
E
D
X_A 59
X_A 585.21
DOC IG P
(SAME AS C
DOCKING D
AS REQUIR
215 DIA
X_A 502
INBOARD PROFILE

Figure 5. A

5177-217D

JE/ HATCH ASSY.
S)

5.75

PRESSURIZED
MPT. VOL. 1740 FT³

XPERIMENTS
SHELF

7.75

LEM-ADAPTOR
INTERFACE (REF.)

ROBE / HATCH ASSY.
M'S) INTERCHANGEABLE WITH
ROGUE / HATCH ASSY.
IED – SEE VIEW E & E'

.O

RACK DESIGN

The rack is supported within the spacecraft LEM adapter at the LEM attach points. The adapter protects the rack from aerodynamic loading and heating during boost. The rack design conditions result from the accelerations encountered during launch and orbital operations loads. The condition that produces the maximum axial acceleration occurs at the end of the first-stage boost of the Saturn V vehicle. The maximum axial limit load factor is 4.7 g. An ultimate factor of safety of 1.5 is used and gives an ultimate design load factor of 7.05 g.

The airlock strength requirement is determined by internal pressure. The 7±1 psi operating pressure requirement is the same as that of Apollo, with the design ultimate pressure 12 psi.

A closure rate sufficient to produce a 1-g limit loading condition was assumed in order to develop orbital docking loads, based upon a total weight of 30,000 lb. The rack internal loads resulting from this condition were less than those of the launch condition and therefore were not critical for design.

AIRLOCK STRUCTURE

The cylindrical airlock is an all-welded pressure membrane of skin-stringer construction. Since the stress level is not critical and practical manufacturing gauges determine the minimum weight, 2219-T87 is used for its weldability. It is supported at the center of the experiments rack by the eight radial beams. Two diametrically opposite pressure tight walk-through doors are provided in the sidewall to permit access to the interior of the rack itself. The stringers in the pressure shell permit the mounting of experiments and associated equipment (such as console, controls, and displays) within the airlock. The 0.032-inch skin thickness of the airlock wall is greater than required to react the static pressure load; however, the airlock may be cycled a great number of times throughout its lifetime, and the extra thickness will give an extra margin of safety for fatigue purposes.

RADIAL BEAMS STRUCTURE

The principal function of the radial beams is to support the airlock and the shelves on which experiments are mounted. The fabrication of the beams is the same as for the Apollo SM, in that they are milled from two-inch-thick 7075-T6 aluminum plate. They have a web thickness of 0.020 inches and stiffeners of 0.040-inch thickness. The stiffener configuration is of a channel cross-section permitting the shelves to be mounted within the channel.

The weight and distribution of all possible combinations of experiments were not defined at the beginning of the program. In order to design a beam for all possibilities, 2500 lb. was applied at the inboard edge. Actual application will tend to be toward the outboard edge, which would produce a less critical condition.

EXTERIOR SKIN

The exterior skin is of conventional skin-stringer riveted construction. The material is 2024-T6 aluminum alloy. The skin thickness is 0.025 inches, with stringers spaces approximately 8.5 inches on center. The stringers are on the exterior of the rack and provide support for the mete-oroid protection system. This system consists of a layer of foam between the stringers and a bumper sheet fastened to the top of the stringers. The stringers provide hard-points for the attachment of experiments directly to the skin if desired.

BULKHEADS

The upper and lower bulkheads are of aluminum honeycomb construction. It provides lightweight rigid construction to transmit longitudinal loads to the beams and lateral loads to the rack LEM adapter mounting points.

RACK CONFIGURATIONS COMPARISON

For all configurations, the basic rack structure is identical; only subsystem installation varies. The variations are shown in Figure 6.

The Configuration 1 rack contains a 13-day supply of food and LiOH and a 4.8 ft^3, 3000 psi repressurant tank in Sector I. If an environmental control system is required for the experimental equipment, ECS radiators would be installed on Sector covers III and VII.

The rack for Configuration D' houses three Block II fuel cells, three Block II cryogenic O_2, and four Block II cryogenic H_2 tanks in Sectors III and VII. Food and crew system expendables for 29 days are located in Sector I. The Sector I cover includes an EPS radiator and associated EPS equipment. ECS radiators are located on Sector covers III and VII if required.

The "C" rack houses only LiOH and crew system expendables in Sector I. No other subsystems are installed in this rack, since the CSM supplies all power repressurization and environmental control to the airlock.

The "D" rack contains Apollo X cryogenic tanks and three 1000-hour fuel cells in Sectors III and VII to increase the flight duration of the vehicle to 45 days. ECS and EPS radiators are installed in the same sector covers as for the D' configuration. A surge tank that can be used for repressurization is located in Sector I with the LiOH and crew system expendables for 45 days.

A summary weight statement for the various configurations is shown in Table 7.

Table 7. Rack Summary Weight Statement

Item	Configuration Weight (pounds)			
	1	C	D	D'
Structure	2155	2182	2241	2240
Electrical power system	304	304	2297	2037
Communications	108	108	153	153
Instrumentation	34	34	34	34
Environmental control	223	127	140	321
Controls and displays	127	127	164	164
Crew systems	20	20	20	20
Useful load	311	714	3091	1508
Subtotal	3282	3616	8140	6477
Contingency	298	290	505	497
Total	3580	3906	8645	6974

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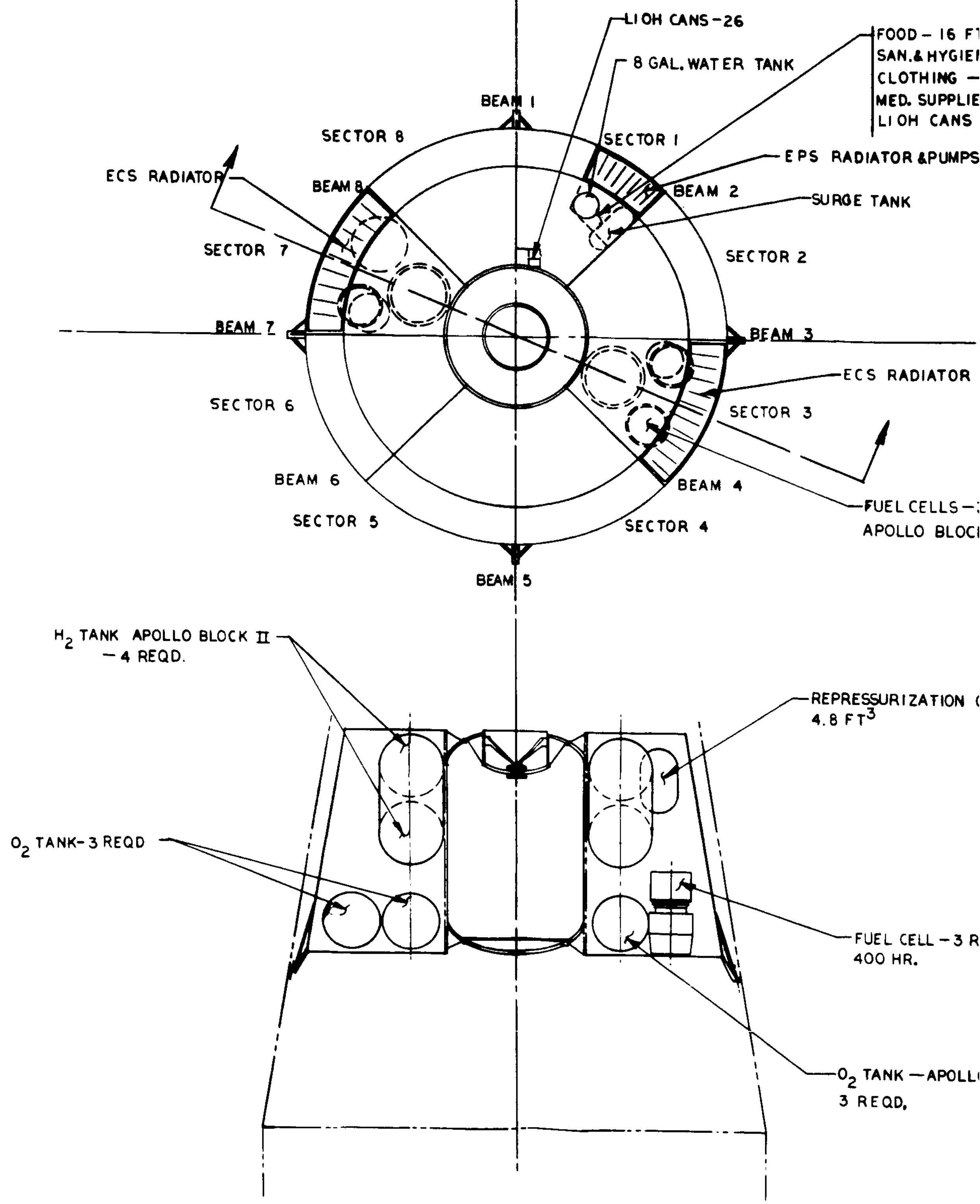
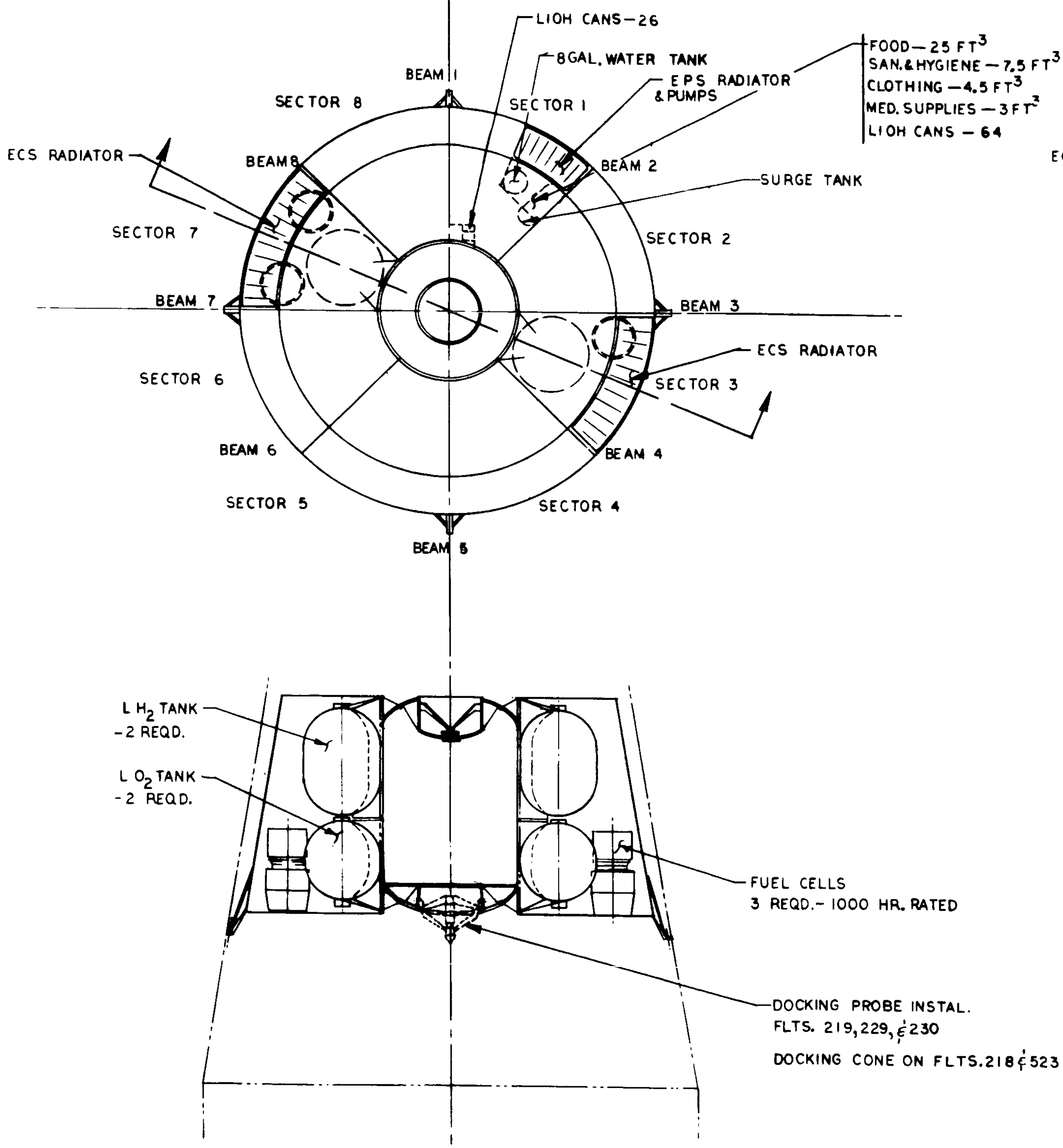
RACK ARRANGEMENT D'



(1)

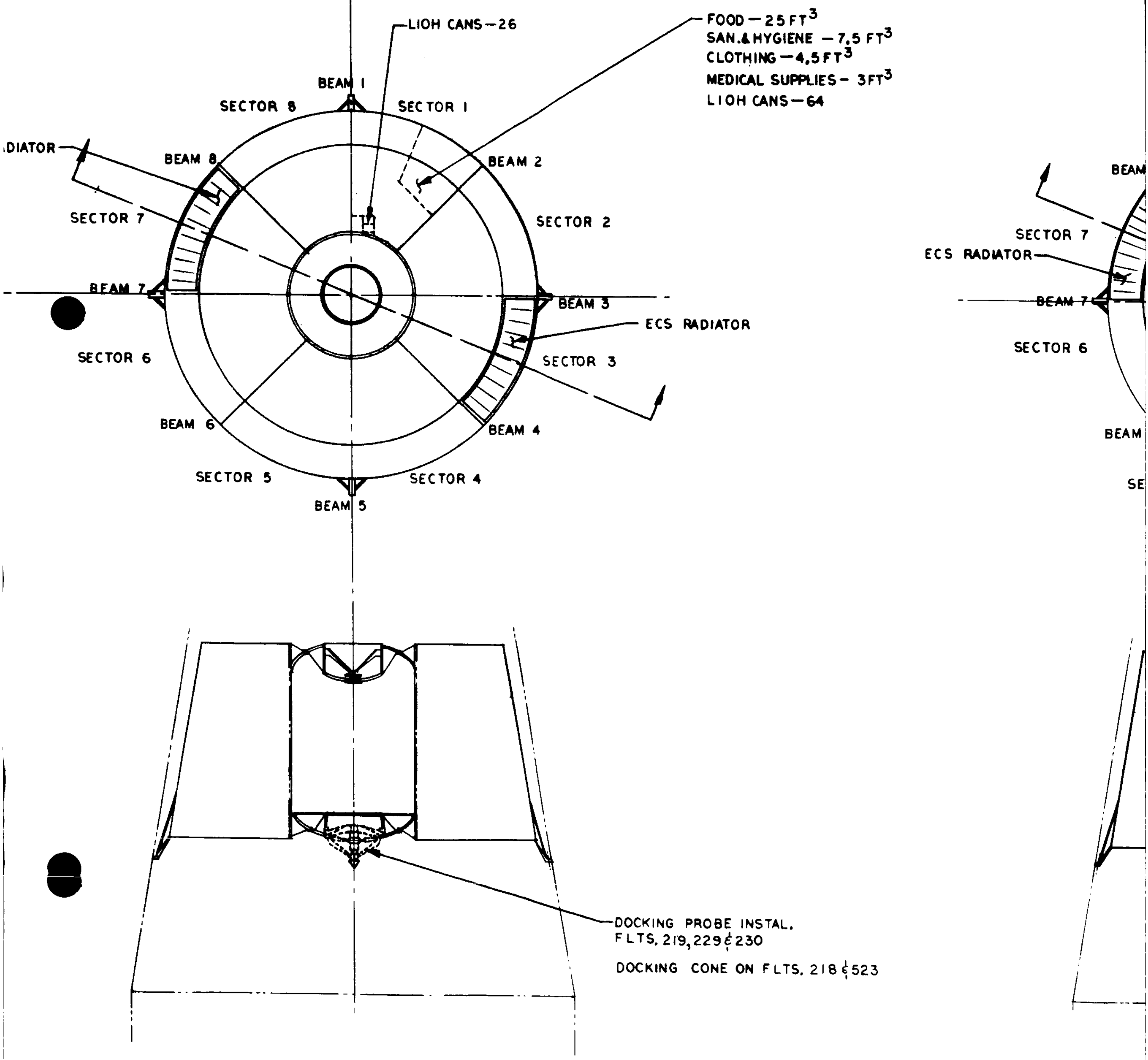
RACK ARRANGEMENT D



3
IE— 7.5 FT^3
4.5 FT^3
S — 3 FT^3
—34
REQD.
II 400 HR.
AS TANK
EQD.
D BLOCK II
ECS R

~~CONFIDENTIAL~~

RACK ARRANGEMENT C



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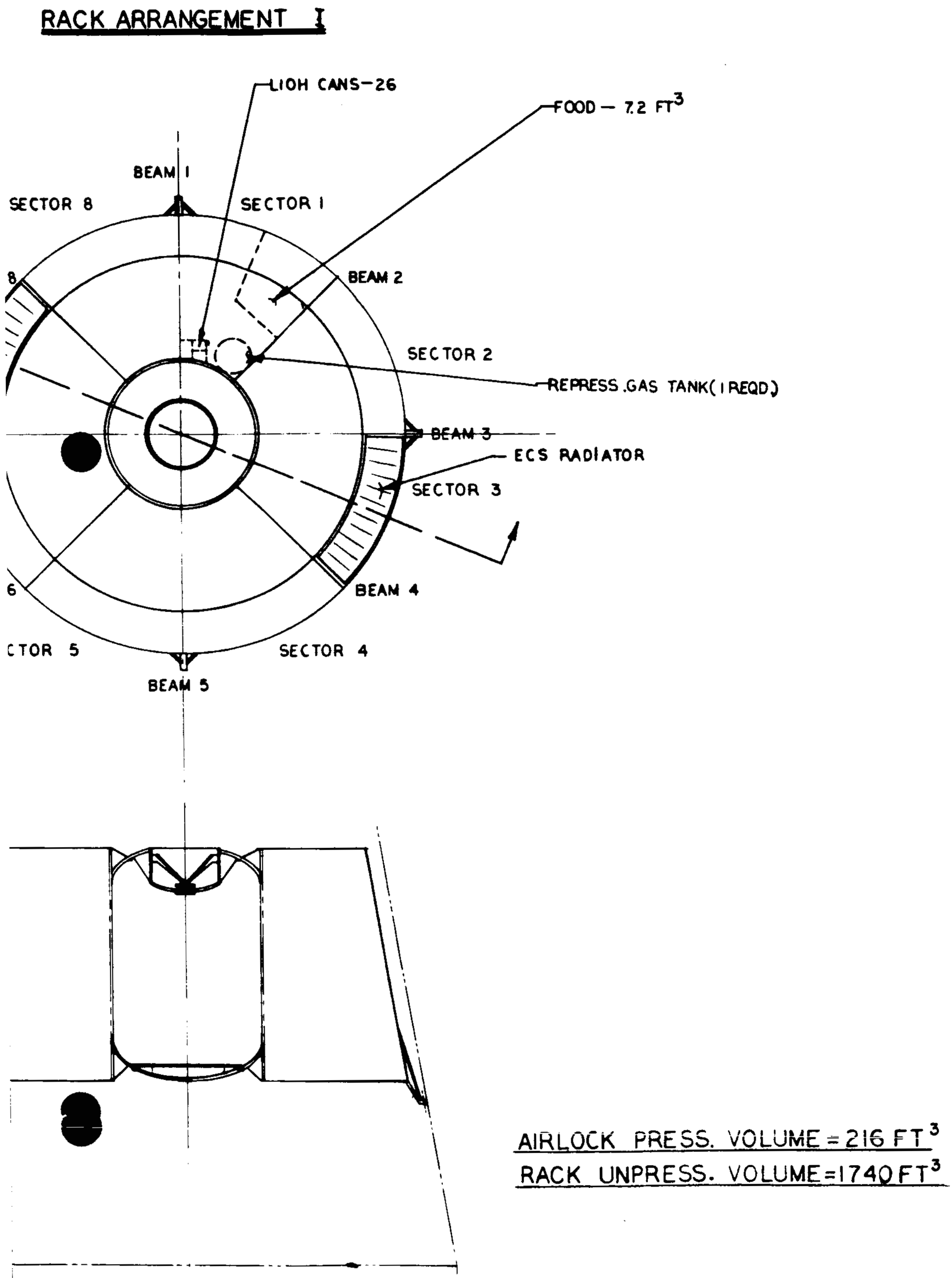

Figure 6. Rack Comparisons

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EXPERIMENTS ACCOMMODATION

Experiments defined by NASA were integrated in the CSM and rack for each flight and each configuration. Detailed layouts and missions descriptions are presented in Volume 3. Initially, it was assumed that those experiments which require no astronaut access might be treated most efficiently by placing them in the pallet designed for Configuration 1 and D. However, as the study progressed, all experiments were found to be compatible with rack installation, resulting in a minimum weight concept. In Flight 518, a pallet was used to house a side-looking radar experiment because preliminary analyses indicated it would not fit in the rack. This resulted in an additional weight penalty of about 3000 pounds. Further design analyses indicated that this equipment could have been placed in the rack.

All NASA missions include the biomedical and behavioral experimental packages (0100 and 0200). These experiments have been integrated into the airlock in a standard arrangement for all flights.

AIRLOCK INTERNAL ARRANGEMENT

The basic airloack (Figure 7) provides a pressurized workspace for controls and displays associated with the various experiments; it also incorporates a subsystems panel for spacecraft monitoring and the control of subsystem elements installed in the rack. The airlock arrangement is essentially mission independent for all NASA flights. Although Configurations 1, C, D', and D have similar airlock requirements, the Configuration D subsystems panel is larger because the power system was added to the rack.

The forward end of the airlock is designed to house a LEM-type drogue cone and dock with the Apollo Block II command module. The aft end of the airlock is designed for the alternate installation of either a LEM-type drogue cone, Apollo type probe, or a hatch—whichever is required by a specific mission. Pressure-tight door with view ports, located at each end of the aisle, provide access to the unpressurized sectors of the rack. The airlock assembly is structurally integral with the rack.

The 216 cubic-foot volume of the airlock was established to meet the requirements of biomedical and human factors experiments. The floor area is 19.4 square feet; with an additional 10.4 square feet under the work table and integrated display panel. Movable saddle-type stools provide body restraints and allow considerable flexibility of crew position. The right-hand stool may be swiveled under the work table if desired.

The internal arrangement provides a righthand and lefthand console space, separated by a center work area. The biomedical and behavioral experiments and the integrated display system are located on the left side of the aisle. The data management panel, the decoder, and data storage recorder are located above the behavioral equipment. A vertical cold plate provides support for the power supply and integrated display generator. Storage area is also available in the upper section. The airlock environmental control unit—consisting of an air circulation fan, catalytic burner, and debris trap—is located in the upper section. The storage area for the TV and still cameras is also in the upper section.

The right side of the aisle provides the work space. Above this space is the subsystem display and control panel. This panel is the only item that is changed in subject configurations.

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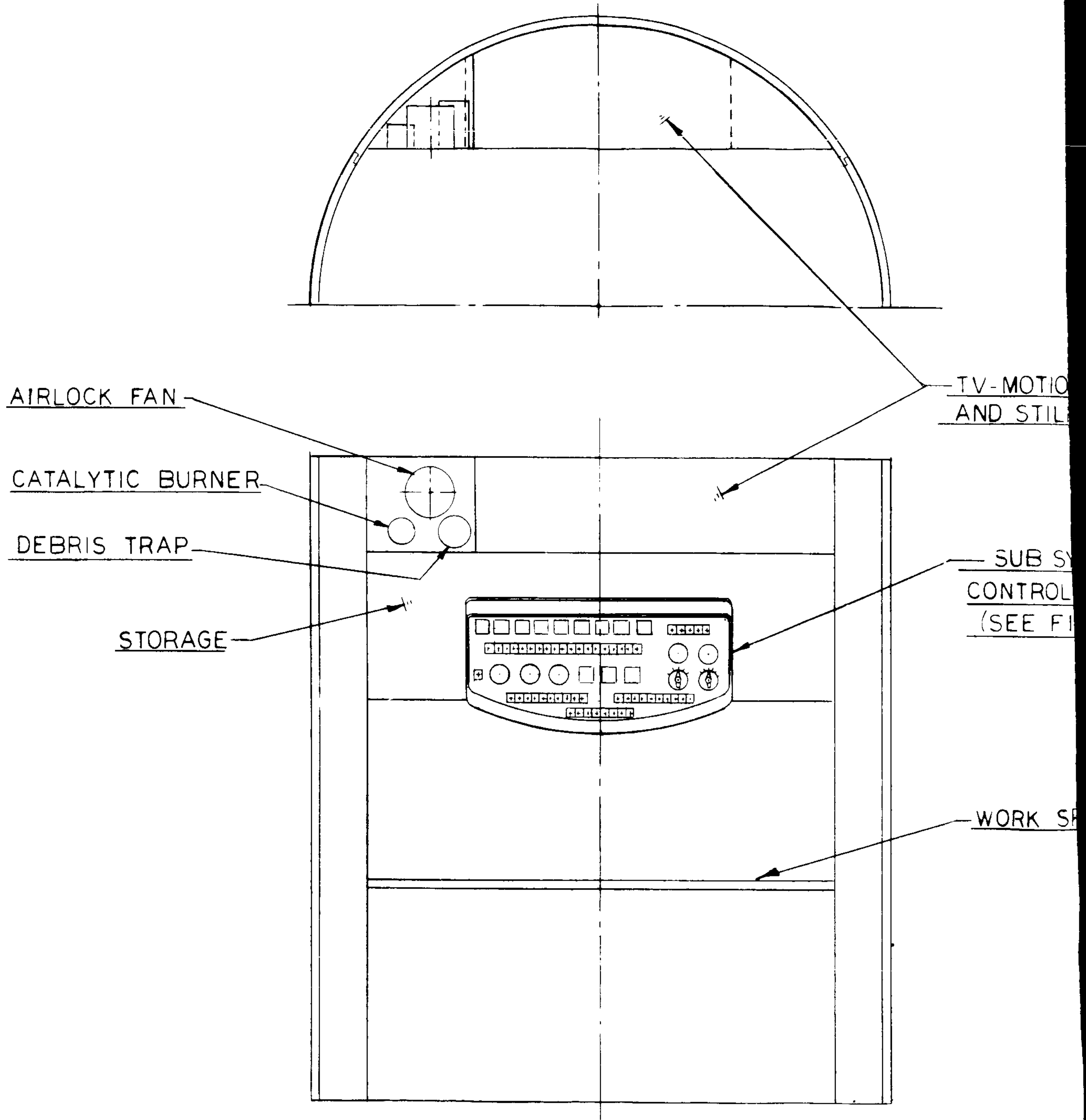

SECTION B - B
RIGHT HAND

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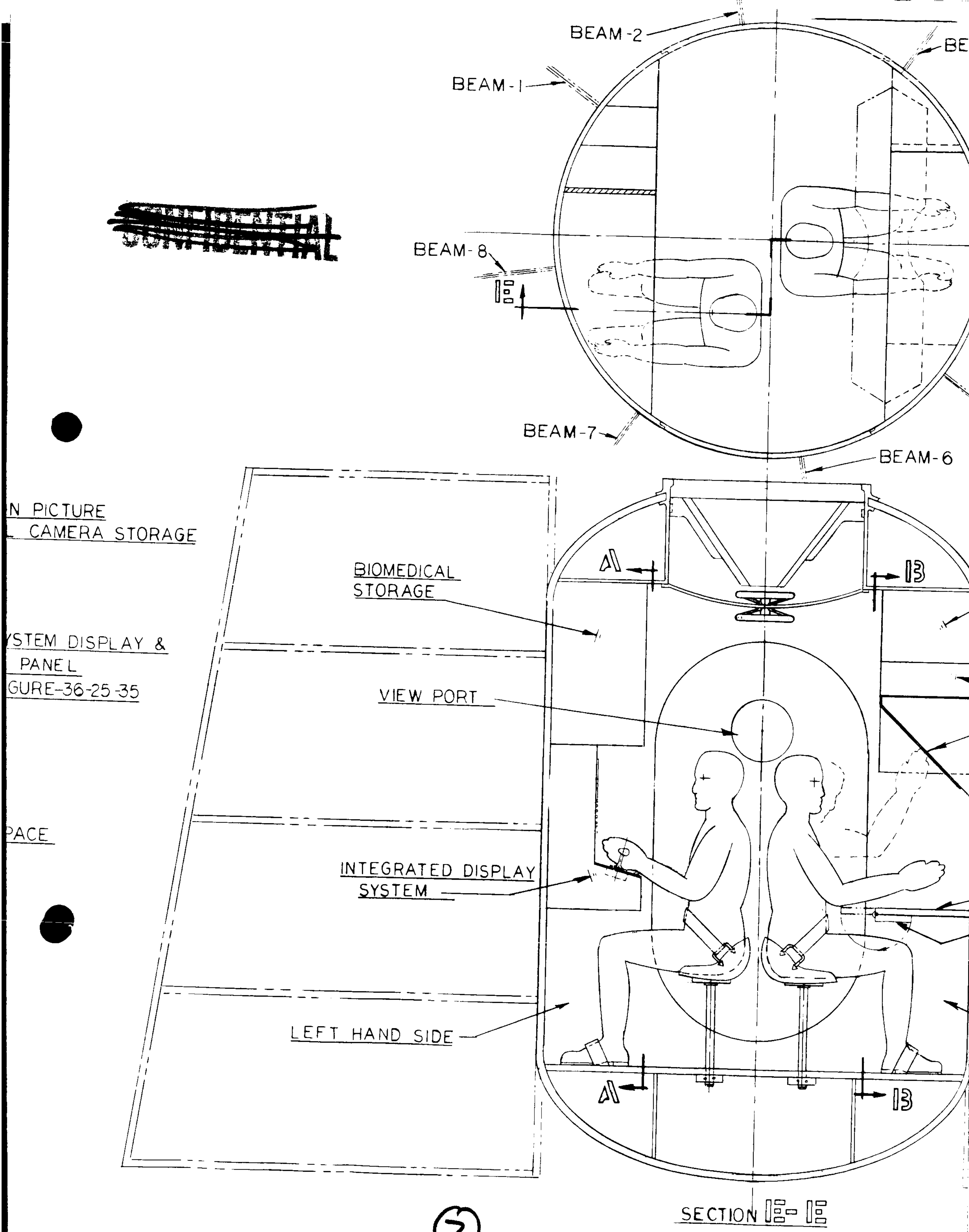

AM-3

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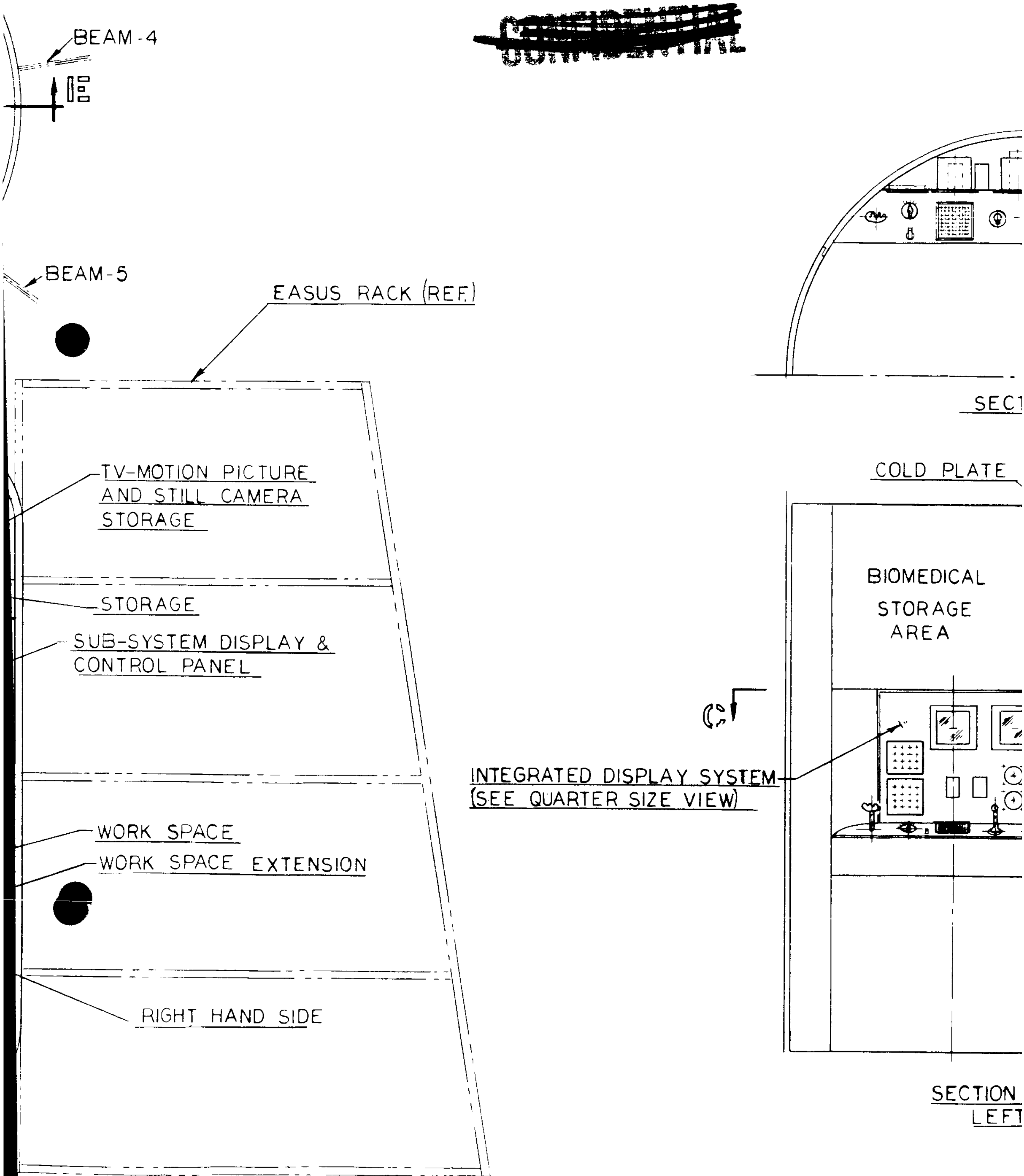
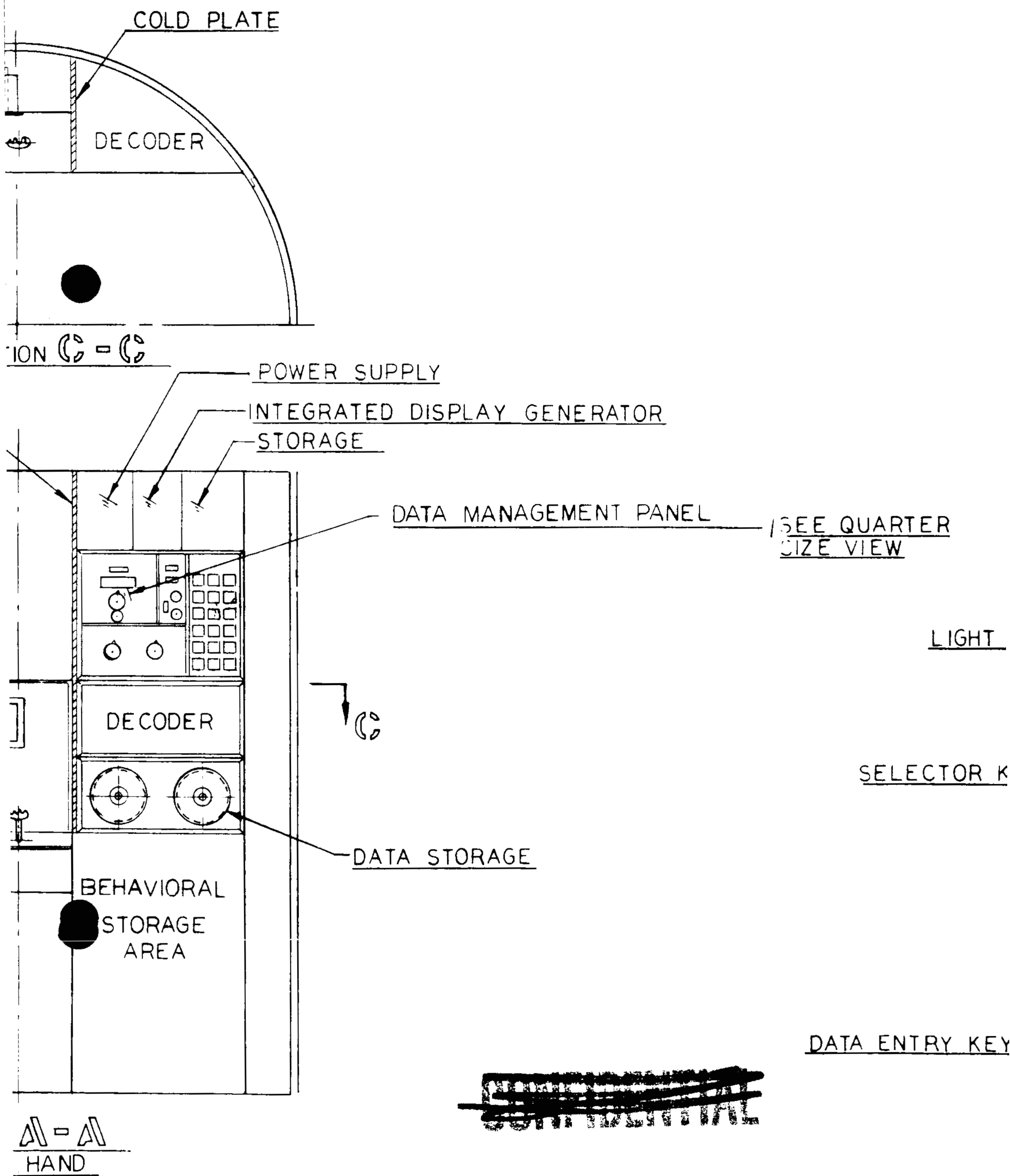
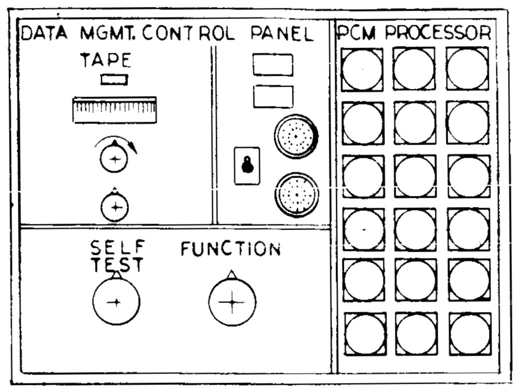
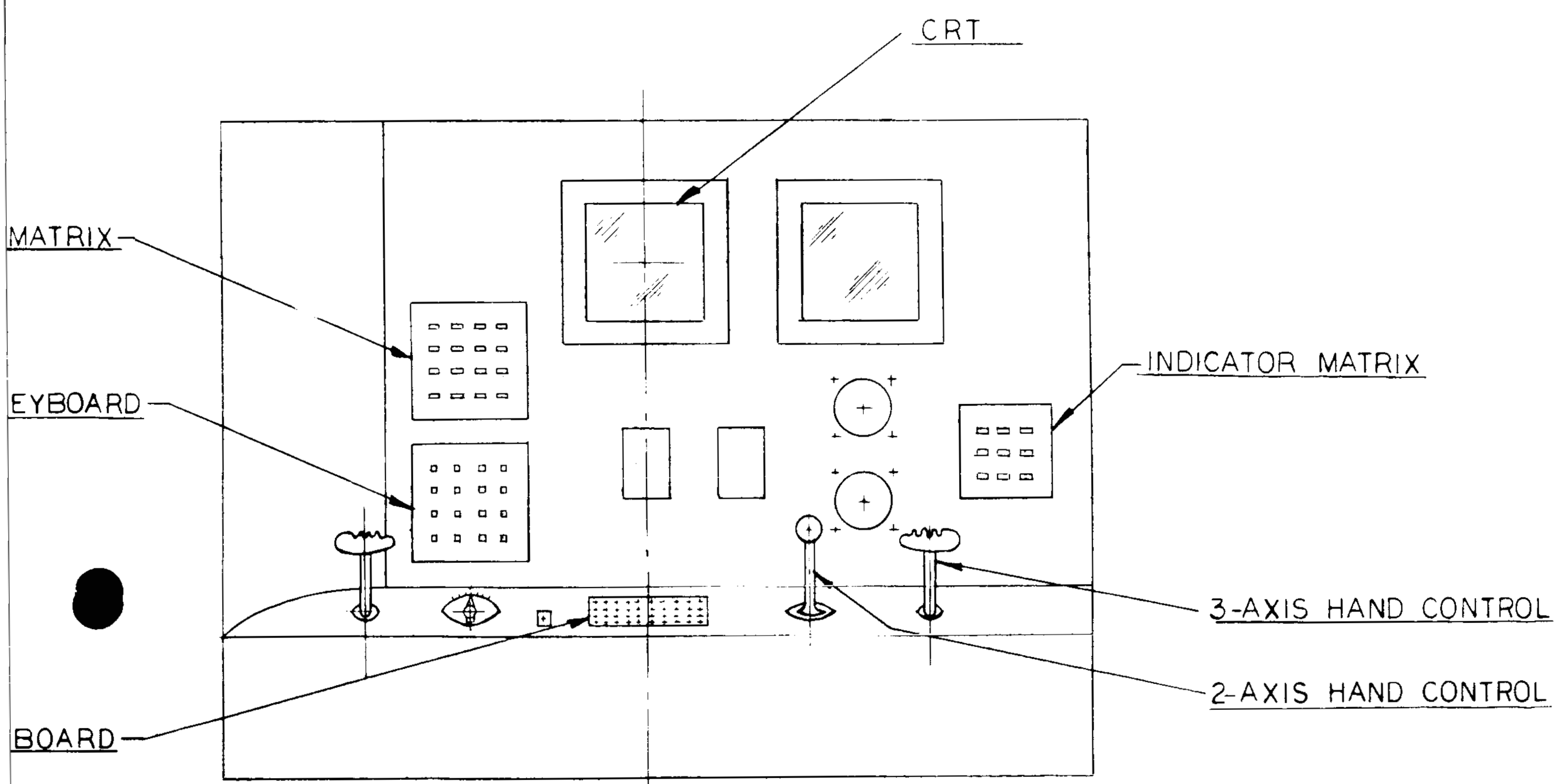



COLD PLATE
DECODER
ION C - C
POWER SUPPLY
INTEGRATED DISPLAY GENERATOR
STORAGE
DATA MANAGEMENT PANEL
SEE QUARTER SIZE VIEW
LIGHT
DECODER
C
SELECTOR K
DATA STORAGE
BEHAVIORAL STORAGE AREA
DATA ENTRY KEY
A - A
HAND

5177-279A



*3 - DATA MGMT. CONTROL PANEL
1/4 SCALE



*2 - INTEGRATED DISPLAY SYSTEM
1/4 SCALE

Figure 7. Airlock Internal Arrangement, AES—Typical NASA Flights

SPACECRAFT PERFORMANCE/WEIGHTS

In this study weight factors were of primary concern because it was not known whether or not each flight—with its full experimental program aboard—could be accomplished within its payload limitations. For the comparison of calculated weights with booster payload capabilities, NASA-furnished launch vehicle performance figures were used so that concurrent studies conducted by Grumman and Boeing would be consistent with this study.

The NASA-specified payloads are shown in Table 8. For the low-inclination Earth orbit flights (Flights 209, 211, 218, 219, 229, 230), the payload for the S-IB was stated to be 32,670 pounds. Flights 219, 229, and 230 (rendezvous flights) must carry an additional 650 pounds of service propulsion system propellant reducing the specified payload capability by that amount. Flights 215 and 221 use the spent Saturn S-IVB stage as a counterweight for the artifical G experiment. The payloads listed for these flights, therefore, include the spent stage weight of 31,185 pounds.

The high-orbit inclination, low-altitude missions (Flights 507, 513, and 518) have a NASA-specified payload capability of 106,495 pounds. This is attained by a programmed yaw steering maneuver during ascent. The ascent trajectory (Figure 8) illustrates the tracking and booster impact problems attendant with such a maneuver. For a two-stage-to-orbit booster, the first stage will impact in the Cuba-Puerto Rico region. The second stage of the three-stage-to-orbit vehicle would impact in Columbia, South America. For comparison, a non-yaw steering ascent trajectory is also shown in this figure. Synchronous orbit capability of 57,250 pounds was specified for Flights 516 and 521. The payload of Flight 523 includes S-IVB propellant.

For Air Force configurations, a weight contingency of 20 percent was added to the calculated weights as specified by the Air Force MOL RFP. Because the Apollo CSM is now in development, this was applied only to the dry rack weight and experiments. The Apollo program March 1965 Weight Statement for the CSM was used as a basis for the various NASA configuration concepts. For NASA flights, a weight contingency of 10 percent was assumed and applied to the dry rack weight and experiments. Summary weights for the overall spacecraft for each flight as shown in Tables 9 through 12 were compared with the specified payloads to obtain a weight margin.

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Table 8. Payload Capabilities Per NASA Specification

Flight	Booster	Altitude (nmi)	Inclination (deg)	Payload (lb)	SM ASC Propulsion (lb)	Remarks
209,211, 218	S-IB	200	28.5	32,670	1,410	
219,229, 230	S-IB	200	28.5	32,670	1,410	No allowance for rendezvous (650 lb)
215	S-IB	200	50	61,343	1,307	Payload includes S-IVB (31,185 lb)
507	S-V	200	90	106,495		Yaw steering
516,521	S-V	19,350	0	57,250	25,200	Two-stage to low earth orbit, 15,800 propulsion for deboost
513	S-V	200	81.5	106,495		Yaw steering, no allowance for echo rendezvous (8,560 lb)
518	S-V	200	-83	106,495		Yaw steering
221	S-IB	200	28.5	62,847	1,339	Payload includes S-IVB (31,185 lb)
523	S-V	200	28.5	219,250		Payload includes S-IVB propulsion

Configuration 1 and D' weights are listed in Table 9. These weights include the weight of batteries necessary for peak power loads required for experiments and the 14-day mission. Flights 211 and 215 have negative weight margins. Consequently, flight duration or individual experiment frequencies must be limited to meet launch vehicle payload capabilities.

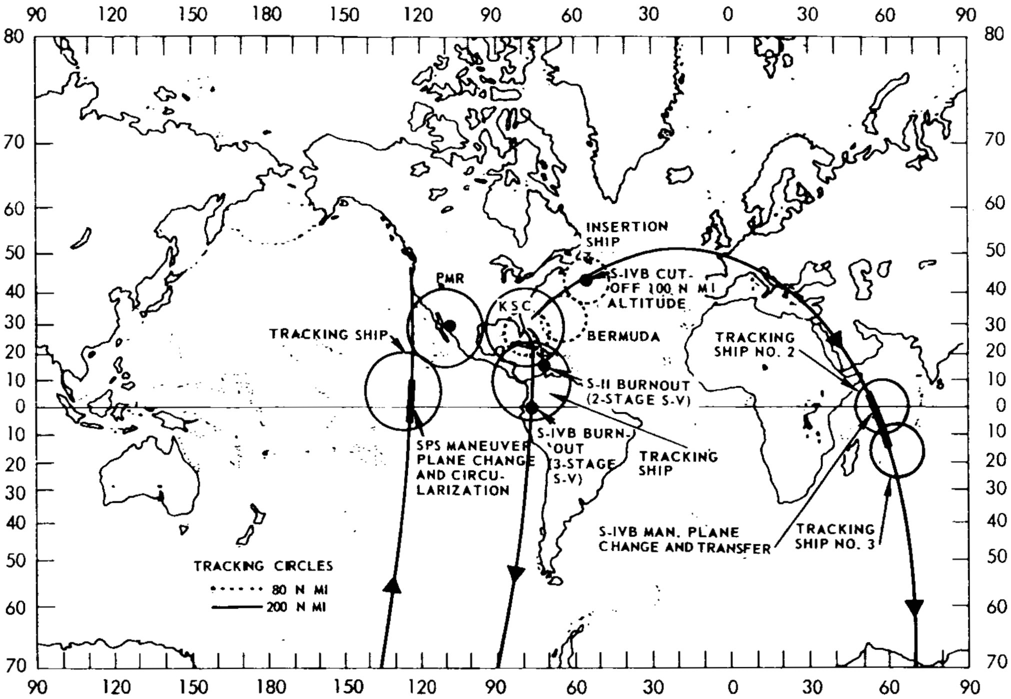

Figure 8. High Inclination Orbit Ascent

In Table 10, summary weights for the full experiment program are presented for Configurations C and D flights scheduled for Saturn IB boosters. All D Configurations show negative weight margins since the gross weights are approximately 2000 to 3000 pounds greater than the C Configurations. Mission durations or experiment frequencies must again be modified to result in positive weight margins.

Weights for Saturn V flights for the C and D Configurations are listed in Table 11. Positive weight margins exist for all flights. Air Force flight weights are presented in Table 12 and exhibit negative weight margins for the 45-day mission. Since the Air Force mission duration requirement is for 30 days, Configuration C can accommodate both flights if the duration is limited to approximately 35 days. By contrast, the duration of Configuration D must be reduced to less than 14 days to meet the payload limitations.

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Table 9. Weight Summary—Configurations 1 and D'

Apacecraft Units	Flight Number					
	209	211 (D')	215	507	509	513
Command module	(10,215)	(10,278)	(10,215)	(10,215)	(9,965)	(10,215)
Empty weight	8,946	9,009	8,946	8,946	8,943	8,946
Useful load	1,269	1,269	1,269	1,269	1,022	1,269
Service module	(9,879)	(11,379)	(9,879)	(9,879)	(9,879)	(9,879)
Empty weight	8,388	8,388	8,388	8,388	8,388	8,388
RCS expendables	838	838	838	838	838	838
Cryogenic expendables	653	653	653	653	653	653
LMS		1,500				
SPS retro propulsion	(1,165)	(1,180)	(1,165)	(1,165)	(15,800)	(1,165)
Rack	(6,397)	(7,797)	(10,506)	(9,455)	(6,060)	(7,242)
Empty weight	3,269	5,466	3,269	3,269	3,269	3,269
Useful load	1,235	1,333	2,159	1,081	548	1,697
Experiments	1,893	998	5,078	5,105	2,243	2,276
SPS propulsion (experiments)	(1,400)	(2,800)	(1,400)	(1,400)	(1,400)	(10,050)
Payload total	29,056	33,434	33,165	32,114	43,104	38,551
Available payload	32,670	32,670	30,158	106,495	57,104	106,495
Margin	+3,614	-764	-3,007	+74,381	+14,146	+67,944

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Table 10. Weight Summary—Configurations C and D, Saturn 1-B Flights

Spacecraft Units	Flight Number									
	218C	218D	219C	219D	221C	221D	229C	229D	230C	230D
Command module	(10,288)	10,303	(10,288)	(10,303)	(10,288)	(10,303)	(10,288)	(10,303)	(10,288)	(10,303)
Empty weight	9,019	9,034	9,019	9,034	9,019	9,034	9,019	9,034	9,019	9,034
Useful load	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269
Service module	(13,382)	(12,038)	(13,382)	(12,038)	(13,382)	(12,038)	(13,382)	(12,038)	(13,382)	(12,038)
Empty weight	8,435	8,921	8,435	8,921	8,435	8,921	8,435	8,921	8,435	8,921
RCS expendables	2,464	2,464	2,464	2,464	2,464	2,464	2,464	2,464	2,464	2,464
Cryogenic expendables	2,483	653	2,483	653	2,483	653	2,483	653	2,483	653
SPS retro propulsion	(1,380)	(1,300)	(1,250)	(1,170)	(1,380)	(1,300)	(1,250)	(1,170)	(1,250)	(1,170)
Rack	7,336	(12,075)	(5,659)	(10,398)	(5,283)	(10,022)	(7,565)	(12,304)	(7,425)	(12,164)
Empty weight	3,357	5,719	3,468	5,830	3,192	5,554	3,468	5,830	3,468	5,830
Useful load	714	3,091	714	3,091	714	3,091	714	3,091	714	3,091
Experiments	3,265	3,265	1,477	1,477	1,377	1,377	3,383	3,383	3,243	3,243
SPS propulsion (experiments)			(2,050)	(650)			(650)	(650)	(650)	(650)
Payload total	32,386	35,716	32,629	34,559	30,333	33,663	33,135	36,465	32,995	36,325
Available payload	32,670	32,670	32,670	32,670	32,670	32,670	32,670	32,670	32,670	32,670
Margin	+284	-3,046	+41	-1,889	+2,337	-993	-465	-3,795	-325	-3,655

Table 11. Weight Summary—Configurations C and D, Saturn V Flights

Spacecraft Units	Flight Number							
	516C	516D	518C	518D	521C	521D	523C	523D
Command module	(10,288)	(10,303)	(10,288)	(10,303)	(10,288)	(10,303)	(10,288)	(10,303)
Empty weight	9,019	9,034	9,019	9,034	9,019	9,034	9,019	9,034
Useful load	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269
Service module	(14,847)	(12,038)	(13,382)	(15,178)	(14,847)	(12,038)	(13,382)	(12,038)
Empty weight	9,900	8,921	8,435	8,921	9,900	8,921	8,435	8,921
RCS expendables	2,464	2,464	2,464	2,464	2,464	2,464	2,464	2,464
Cryogenic expendables	2,483	653	2,483	653	2,483	653	2,483	653
Pallet				3,140				
SPS retro propulsion	(15,800)	(15,800)	(1,335)	(1,170)	(15,800)	(15,800)	(1,335)	(1,170)
Rack	(13,126)	(17,865)	(14,668)	(19,286)	(6,535)	(11,274)	(12,324)	(17,063)
Empty weight	3,192	5,554	3,192	5,554	3,192	5,554	3,357	5,719
Useful load	714	3,091	714	3,091	714	3,091	714	3,091
Experiments	9,220	9,220	10,762	10,641	2,629	2,629	8,253	8,253
SPS propulsion (experiments)			(4,200)	(4,200)				
Payload total	54,061	56,006	43,873	50,137	47,470	49,415	37,329	40,574
Available payload	57,250	57,250	106,495	106,495	57,250	57,250	219,250	219,250
Margin	+3,189	+1,244	+62,622	+56,358	+9,780	+7,835	+181,921	+178,676

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Table 12. Weight Summary—AF Flights/45-Day Duration

Spacecraft Units	Flight Number			
	AF-1(C)	AF-1(D)	AF-2(C)	AF-2(D)
Command module	(10, 288)	(10, 303)	(10, 288)	(10, 303)
Empty weight	9, 019	9, 034	9, 019	9, 034
Useful load	1, 269	1, 269	1, 269	1, 269
Service module	(12, 138)	(10, 739)	(11, 315)	(9, 916)
Empty weight	8, 490	8, 921	7, 994	8, 425
RCS expendables	1, 165	1, 165	838	838
Cryogenic expendables	2, 483	653	2, 483	653
SPS retro propulsion	(1, 380)	(1, 380)	(1, 380)	(1, 380)
Rack	(9, 214)	(14, 170)	(9, 882)	(14, 838)
Empty weight	3, 482	6, 061	3, 482	6, 061
Useful load	714	3, 091	714	3, 091
Experiments	5, 018	5, 018	5, 686	5, 686
SPS propulsion (experiments)	(1, 400)	(1, 400)	(1, 400)	(1, 400)
Payload total	34, 420	37, 992	34, 265	37, 837
Available payload	32, 670	32, 670	32, 670	32, 670
Margin	-1, 750	-5, 322	-1, 595	-5, 167

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SUBSYSTEMS ANALYSIS

This section summarizes the results of the subsystems investigations performed during the AES study. The subsystem definitions used are based upon Apollo Block II and life extension-associated revisions as determined in the previous Apollo X study. Of primary emphasis in the program were the ramifications attendant with NASA-defined ground rules relating to the location and operation of selected subsystems; i.e., relative to placement within the command-service module (CSM) or on the experimental appendage (rack, LEM, or laboratory module).

The initial philosophy established by NASA at the beginning of this study can be summarized for each spacecraft/subsystems configuration as follows:

Configuration 1 - Use Block II subsystems without change and minimize command module changes caused by interfaces with an external device. Because the Block II subsystems are designed for a mission of 14 days, Configuration 1 applies only to missions with nominal durations of 14 days.

Configuration C - Use Apollo X type subsystems (per earlier NAS9-3140 studies) in the CSM for life extension, and add only subsystems peculiar to experiments in the external device. Configuration C should have a nominal mission duration of 45 days.

Configuration D - Use Block II subsystems without change in the CSM, and use Apollo X type subsystems in the external device to both achieve life extension and to provide for experiment functions. This configuration should have a nominal mission duration of 45 days.

In addition to Configurations 1, C, and D, special consideration was required for Flight 211 that calls for a 30-day duration scheduled early in the AES program. Because Configuration 1 cannot endure for 30 days and because Apollo X type subsystems would not likely be available for the scheduled early launch of this flight, another configuration (D') was defined. Configuration D' uses Block II subsystems in the CSM and achieves the extended duration by placing additional Block II subsystems in the external device with prototype modifications of critical CSM subsystems.

Additionally, several other ground rules were postulated by NASA. First, a pure oxygen (5-psia) atmosphere was to be used in all configurations, and second, the guidance and navigation system should be retained in all configurations on all flights. Thirdly, 1000-hour fuel cell stacks should be used in the external device for Configuration D and in the service module for Configuration C. Fourth, the external device should have an independent thermal control system for equipment and experiments housed therein.

The recommended Block II subsystem changes resulting from the previous Apollo X study are summarized in Table 13. Only those changes that could be substantiated by parametric analyses are presented. In other cases, certain changes are presently not indicated; however, subsystem suitability must be verified through testing under Apollo X mission-simulated environment and duration. Therefore, Table 13 provides only an initial tabulation of required changes; testing may reveal the necessity for additional modifications.

Several comments regarding this modification list are apropos for clarification purposes. The Earth-landing system requires the addition of volatile material to the parachute compartment to maintain the compartment pressure after 14 days. Therefore, this is a required change for Configuration D, D′, and C. Because of the single-gas ground rule, the N_2 system (used in Apollo X studies) is not used in Configurations D and C.

The G&N and SCS modifications were either the result of extended durations or, as in the case of the lunar polar orbit mission, the result of severe mapping mission requirements. Some flights, particularly Flight 518, required a tighter attitude hold than was encountered in the Apollo X study. The Apollo X power system used 400-hour cells rather than 1000-hour cells; therefore, the number of fuel cell stacks required for a given mission success probability for the 45-day mission duration can be reduced.

As the study progressed, it became apparent that the NASA initial subsystems philosophy required modification. In Configuration D, the use of the external device as a means for subsystem extension proved meaningless or undesirable in some cases. For example, if the volatile substance for pressure maintenance of the parachute compartment were placed in the external device (with some sort of piping), an obviously undesirable complexity would result. A similar situation would exist with the addition of a redundant compressor (in the external device) for the CSM environmental control system unit and the resulting installation of piping between the two modules. Hence, additional ground rules regarding the Configuration D subsystem modifications were devised early in the study.

Table 13. Apollo X Subsystem Changes

Subsystem	Earth Orbit		Lunar Orbit	
	Low Inclination (45 days)	Polar (45 days)	Low Inclination (20-Day Total)	Polar (34-Day Total)
Comm/Data	Delete hi-gain antenna and rendez-vous equipment.	Delete hi-gain antenna and rendezvous equipment.	No change	Delete rendezvous equipment.
ELS	Add volatile material.	Add volatile material.	Add volatile material.	Add volatile material and heaters.
ECS	Modify compressor. Add cabin fans. Add N_2 system.	Modify compressor. Add cabin fans. Add N_2 system.	No change	Modify compressor. Add cabin fans and N_2 system.
G & N	Remove system	Use modified IMU & AGC	Use modified IMU & AGC	Use modified IMU & AGC.
Power	5 Fuel cells with in-space start. New cryogenic tanks	5 Fuel cells with in-space start. New cryogenic tanks	Add 1 set Block II cryogenic tanks	5 Fuel cells with in-space start. New cryogenic tanks
Propulsion	Use small SPS tanks. One helium bottle only.	Use 1/2-size SPS tanks. One helium bottle only	No change	No change
RCS	No change	Use LEM tanks (2 sets/quad).	No change	Use LEM tanks (2 sets/quad).
SCS	Modify electronics for G & N capability.	Modify electronics for horizon-scan system and redundancy.	No change	Modify electronics for horizon-scan system and redundancy.

The following additional ground rules have been utilized in the AES study:

1. Environmental control system (ECS)

   Additional suit loop compressors will be installed in the CM. Suit system requirements will be considered, but no suit connections are required in the external device.

   All LiOH and food, except for 3 man-days, will be stored in the external device.

Spare circulating fans will be stored in the CM.

All H_2 and O_2 in excess of 14 days are located in the external device.

Laboratory and LEM contractors will provide CM/external device atmosphere exchange.

No provisions shall be made for atmosphere exchange when the CM/external device interlock hatch is closed. It should be possible to maintain pressure for either module.

Extravehicular activities will be accomplished using the external device as an air lock. The LEM and lab contractors will provide gaseous oxygen as required for short-time repressurization.

The external device will provide for recharging the PLSS.

2. Electrical power system (EPS)

Fuel Cell changes include the addition of in-flight start and 1000-hour cells. Configuration C shall use 1000-hour (P&W) cells with and without in-space start. Configuration D shall employ 400-hour fuel cells in the SM and 1000-hour cells in the external device. Configurations 1 and D .shall use 400-hour cells with or without in-space start.

The cryogenic system shall use Block II tanks on Configuration 1 and D' and Apollo X type tanks on Configurations C and D.

3. Stabilization and control system (SCS)

The G&N system will be incorporated for all flights whether required or not.

All subsystem changes and additions will be made in the CSM, including the storage of spares.

Course alignment of the vehicle for the experiments will be accommodated by the G&N. If required, the experiment will provide for fine alignment.

4. Reaction control system (RCS)

The service module RCS will be utilized as much as possible; service module tankage changes will be allowed.

The LEM, RCS, and SCS electronics will be utilized in conjunction with the CSM SCS (also for Configuration C).

Based on the preceding ground rules and philosophy, the subsystems studies established the required changes to the CSM subsystems and generated parametric data concerning the subsystems required on the external device (rack, LEM, or laboratory module).

COMMUNICATIONS AND DATA SYSTEM

The communications and data subsystem analysis was based on four principal factors: (1) types and rates of information to be transmitted, (2) characteristics, (3) ground network capability, and (4) spacecraft equipment. Two areas were investigated — ground network coverage and spacecraft equipment.

GROUND NETWORK COVERAGE

The NASA ground control philosophy asserts that coverage is required before, during, and after thrusting and once an orbit. Since NASA specified the boost and recovery trajectories, no assessment of coverage was attempted for these phases; however, the requirement for system checks during every orbit was considered.

The ground coverage for all altitudes and inclinations of the flights was computed. Two extremes of coverage are shown in Tables 14 or 15. These tables illustrate the coverage for VHF-AM (voice) stations and S-band (tracking, TV, telemetry, and command) stations. A typical slice of the mission is presented with the first orbit starting at the latitude and longitude of Cape Kennedy. In addition, the stations for flight control are specified. The philosophy here is to isolate in time the flight control data. For example, on Orbit 5 in Table 14, Kauai would be used for flight control or system check. No experimental data would be transmitted to this station on this particular orbit. The remainder of the stations providing coverage would be used for experimental data and commands. It is also noted that for polar orbits (87.8-degree inclination), there are orbits that provide no flight control capability—e.g., Orbits 11 and 13).

The coverage for synchronous orbits is provided by the deep space stations. These orbits have continuous coverage, and flight control data could be separated by providing for its transmission at particular times each day.

Table 16 illustrates ground coverage for the Air Force flights. The AF stations must be used because of the secure nature of the experimental data, the high data rates required for the large amount of experimental data, and the incompatibility of the NASA ground stations. The AF sites will be used for experimental data and command; NASA stations will be used for flight control. The time slice in Table 16 starts at Cape Kennedy latitude and longitude.

[redacted]

Table 14. NASA Ground Station Coverage* — 200 Nautical Miles, i = 28.5 Degrees

Station	Orbit Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VHF-AM (VOICE)																				
Kano	6.6										6.0			3.0	6.7	6.9				
Canton Island	7.4															6.9				
Pt. Mugu Pt. Arguello	2.9	6.2	6.8	6.1													5.6	6.7	6.6	4.8
White Sands Corpus Christi	7.4	7.5	7.4	6.5											5.7	7.4	7.5	7.5	7.1	
San Salvador Grand Turk	6.5	7.1	7.4										4.3	7.4	7.2	6.6	6.8	7.5	6.6	
S-BAND (TRACKING), TELEMETRY, TV, VOICE COMMAND																				
Canberra													5.0	6.6	6.7					
Guam			4.2	7.4	6.3	1.9			6.1 (FC)	7.5 (FC)									7.0	7.1
Bermuda	7.1	6.1												4.8	6.8	7.1	6.7			
Madrid												4.3	6.0	5.9						
S-BAND AND VHF-AM																				
Kennedy	7.5	7.5	7.0											4.1	7.1	7.5 (FC)	7.5 (FC)	7.4 (FC)	5.6	
Wallops Island	6.1	5.5													4.2	6.0	5.9			
Canary Island											4.1 (FC)	6.8 (FC)	7.5 (FC)	7.5 (FC)	7.4 (FC)	6.3				
Madagascar	7.5	7.9	5.5	4.8	7.0	7.4											7.3	5.9	5.3	6.5
Carnarvon	7.3	7.5												7.2	7.5	7.3	7.4	7.2		
Kauai		6.6	7.5	6.9	6.8 (FC)	6.8 (FC)	7.0 (FC)	6.1 (FC)									5.3	7.5	7.2 (FC)	6.8 (FC)
Guaymas	7.1 (FC)	7.5 (FC)	7.5 (FC)	7.3 (FC)												6.6	7.5	7.5	7.5	6.6

(FC) - Flight control

* Time in minutes

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Table 15. NASA Ground Station Coverage*— 200 Nautical Miles, i = 87.8 Degrees

Station	Orbit Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VHF-AM (VOICE)																				
Kano					7.5								4.3							
Canton Island																				
Pt. Mugu Pt. Arguello			7.4							5.1								3.6	6.1	
White Sands Corpus Christi		7.2							5.2								4.1	5.1		
San Salvador Grand Turk	6.7							5.6								6.4	2.9			
S-BAND TRACKING), TELEMETRY, TV, AND VOICE COMMAND																				
Canberra						3.8								4.1						
Guam							7.5 (FC)								2.5 (FC)					
Bermuda	4.3				5.9			7.5 (FC)								7.4 (FC)				
Madrid			6.7 (FC)											5.8						
S-BAND AND VHF-AM																				
Kennedy	7.4 (FC)								7.3 (FC)								7.1 (FC)			
Wallops Island	7.4							5.1								5.3	6.5			
Canary Island						7.5 (FC)								7.5 (FC)						
Madagascar																			7.5 (FC)	
Carnarvon																7.4				
Kauai				4.9 (FC)	5.5 (FC)							6.8 (FC)								7.3 (FC)
Guaymas		5.9 (FC)	4.9							7.3 (FC)								7.4 (FC)		

(FC) Flight Control
* Time in minutes

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Table 16. AF Ground Station Coverage* — 200 Nautical Miles, i = 28.5 Degrees

Station	Orbit Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SECURE STATIONS																				
Okinawa						6.2	7.5	7.5	6.8	4.1										
Hawaii		6.6	7.5	6.9	6.8	6.8	7.0	6.1									5.3	7.5	7.2	6.8
Pacific Missile Range	2.9	6.2	6.8	6.1													5.6	6.7	6.6	4.8
Antigua	5.1	6.8	7.5										7.2	7.1	5.6	4.7	6.1	7.5	6.5	
NONSECURE STATIONS																				
CKAFS	7.5	7.5	7.0											4.1	7.1	7.5	7.5	7.4	5.6	
Carnarvon	7.3	7.5												7.2	7.5	7.3	7.4	7.2		
FLIGHT CONTROL (NASA STATIONS)																				
Guam									6.1	7.5										
Canary Island											4.1	6.8	7.5	7.5	7.4	6.3				
Kauai					6.8	6.8	7.0	6.1												
Guaymas	7.1	7.5	7.5	7.3													7.5	7.5	7.5	6.6

*Time in minutes

Table 17 summarizes the coverage for both NASA and AF stations in terms of the number of hours per day available for experimental purposes. The experimental integration analyses show that this coverage is more than adequate.

SPACECRAFT EQUIPMENT

The Block II and Apollo X communications/data systems are quite similar. It was found in the Apollo X study that, even with the high usage of 4 hours per day (equivalent to 28.5-degree inclination, 200-nautical-mile orbit), the Block II equipment has a sufficiently high reliability for about 57 days. For all configurations, there are modifications to some black boxes to accommodate interconnections required by the external device.

Table 17. Communications/Data Capability*

Mode	200 Nautical Mile Orbits					Synchronous Orbits
	28.5°	50°	81.5°	87.8°	96.5°	
NASA						
S-band down 51.2 KBS PCM + TV + tracking + analog	4.0	2.9	1.1	1.0	1.1	Continuous
VHF-AM (voice)	5.2	3.1	1.6	1.5	1.6	None
S-band up 1 KBS	4.0	2.9	1.1	1.0	1.1	Continuous
AIR FORCE						
S-band down 1,024 KBS FM/FM analog + ranging + voice	1.6 (Secure) 1.0 (Nonsecure)	—	—	—	—	—
S-band up 1 KBS + voice	1.6 (Secure) 1.0 (Nonsecure)	—	—	—	—	—

*Hours per day, experiment function only

[redacted]

The Apollo system is designed to be compatible with the existing and planned NASA stations. Data, tracking, command, and voice functions are transmitted or received on S-band frequencies. The vehicle also carries VHF-AM voice equipment. Telemetry can be transmitted at either 51.2 KBPS or 1.6 KBPS. Command data are received at 1.0 KBPS (ground transmission rate).

The power requirements of the communications equipment vary with altitudes. For synchronous orbits, the high power output of 20 watts (requiring a power amplifier input power of 80 watts) is required in conjunction with the high gain antenna and a deep space station to provide adequate margin. For 200 nautical-mile-altitude orbits, the power amplifier can be bypassed.

NASA Flights

Figure 9 illustrates the communication and data system for all NASA flights. The basic Apollo Block II system is on the left portion of the diagram. It is noted that the high gain antenna is used only for the synchronous orbit flights.

The external device requires the use of a set of standard equipment that translates experimental data into the proper format or receives up data in the Apollo format for decoding. Experimental data are either conditioned (to 0-5 volts) and stores in analog form for later transmission or routed to the PCM telemetry for conversion to the proper digital format and then stored for later transmission. Digital experimental data are formatted by the PCM unit and stored for later transmission. In addition, the storage loop can be bypassed if real time data transmission is desired. The PCM and data storage units in the external device are connected to the Apollo CSM premodulation processor.

Up-data commands are received via the CSM S-band equipment and are routed to both the CSM command decoder and the command decoder in the external device. The first three information bits in the message (actually, the first 15 bits — due to coding) identify the space vehicle address. The commands for the external device would use a different vehicle address from that of the CSM. Once the command data are decoded, the information would be sent to the experiments programmer.

To allow the crew to communicate between the CM and the external device, an audio center is included in the external device and is wired to the audio center in CM. Finally, the CM central timing unit provides time synchronization signals to the PCM unit, the data storage equipment, and the command decoder of the external device.

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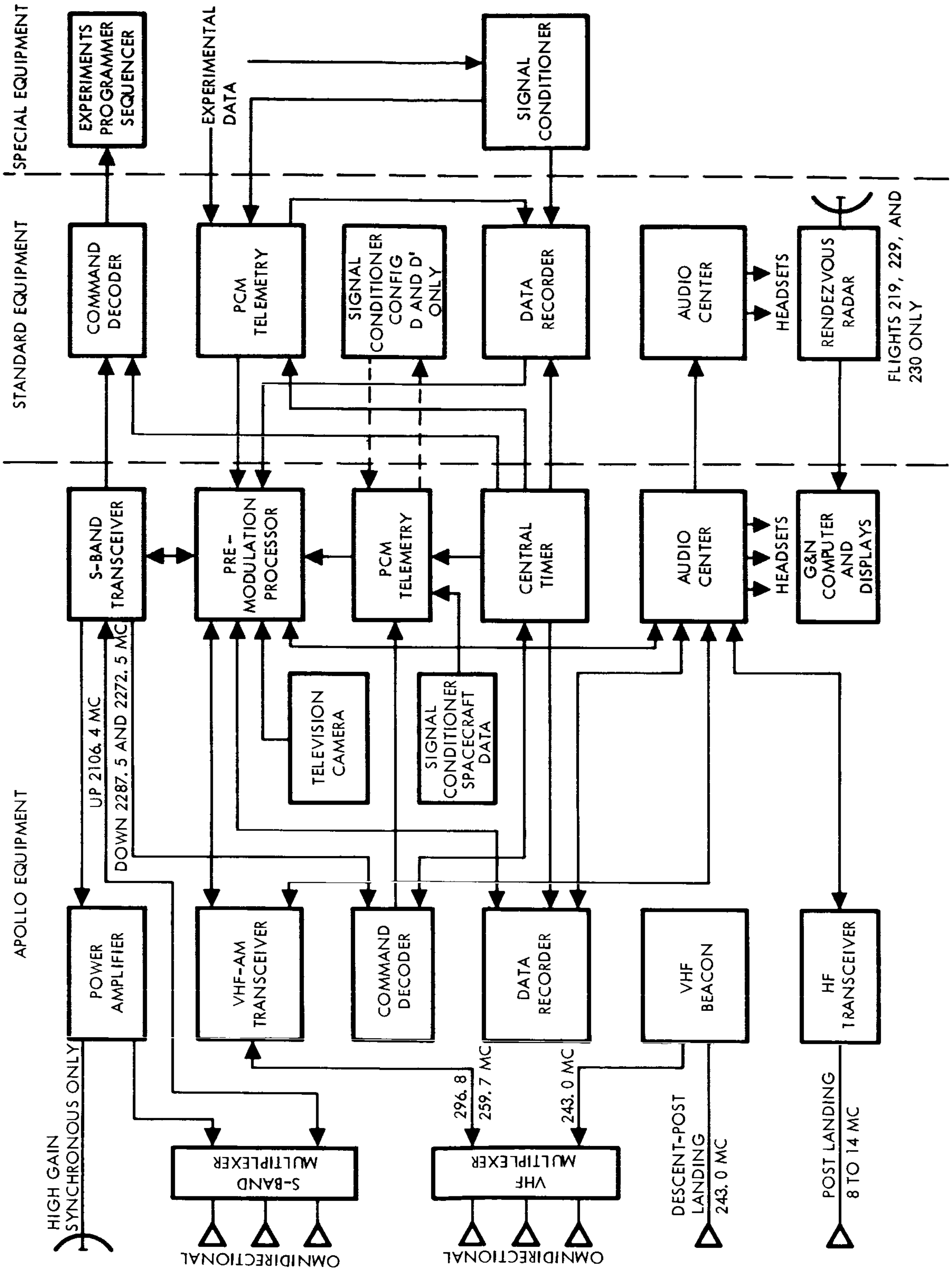

Figure 9. Communication Data System—Apollo Spacecraft

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For Configurations D and D[1], a subsystems signal conditioner is included in the external device. It receives signals from subsystems in the external device, such as fuel cells, and also signals from the cryogenic storage system, and transmits the data to the CM PCM unit. These data are included with CSM system data and are transmitted to the flight control ground station.

For Flights 219, 229, and 230, the LEM randezvous radar is located on the external device. Flights 218 and 523 would have the Block II CSM rendezvous transponder located on the external device.

AF Flights

The philosophy of data system design and operation for Air Force experiment data recovery and command is similar in some respects to that adopted for NASA experiment data operations. System design ground rules were: (1) a system providing real-time and stored-data transmission of acquired experiment data is required; (2) ground network modifications are to be minimized by adoption of a data system currently in use or under consideration by the Air Force; (3) some of the data rates for Air Force experiments are very high and beyond the capacity of conventional telemetry systems, but the bulk of experiment telemetry requirements (perhaps 90-95 percent is modest. A "standard" data system will be provided that is capable of satisfying all but the extreme situations; these will be handled in an individual, special equipment bases.

The space-ground link subsystem (SGLS) vehicle and ground equipment recently developed for AFSC-SSD by Space Technology Laboratories is intended for application to all SSD manned and unmanned programs, and was selected, with some modification, for this program.

While there is a gross similarity between the NASA system and SGLS, differences in rate and format preclude a simple interface between SGLS and the Apollo spacecraft and ground data subsystems. The experiment data/communication subsystem for Air Force experiments is entirely separate from the spacecraft subsystems, with no functional interface and no connection except for power.

Figure 10 presents a block diagram of the AF experiment data/communication subsystem. Except for the addition of data storage equipment and a timer, the SGLS is used as is. The experiment data acquisition scheme calls for real-time telemetry during spacecraft-ground network access at 4 kbps or 256 kbps. For playback at 256 kbps, data may be recorded at 4 kbps, 32 kbps, or 256 kbps. As with the NASA experiment missions, data from external device subsystems associated with the experiments will be subcommutated and entered in the Apollo telemetry subsystem rather than in that provided for the experiments.

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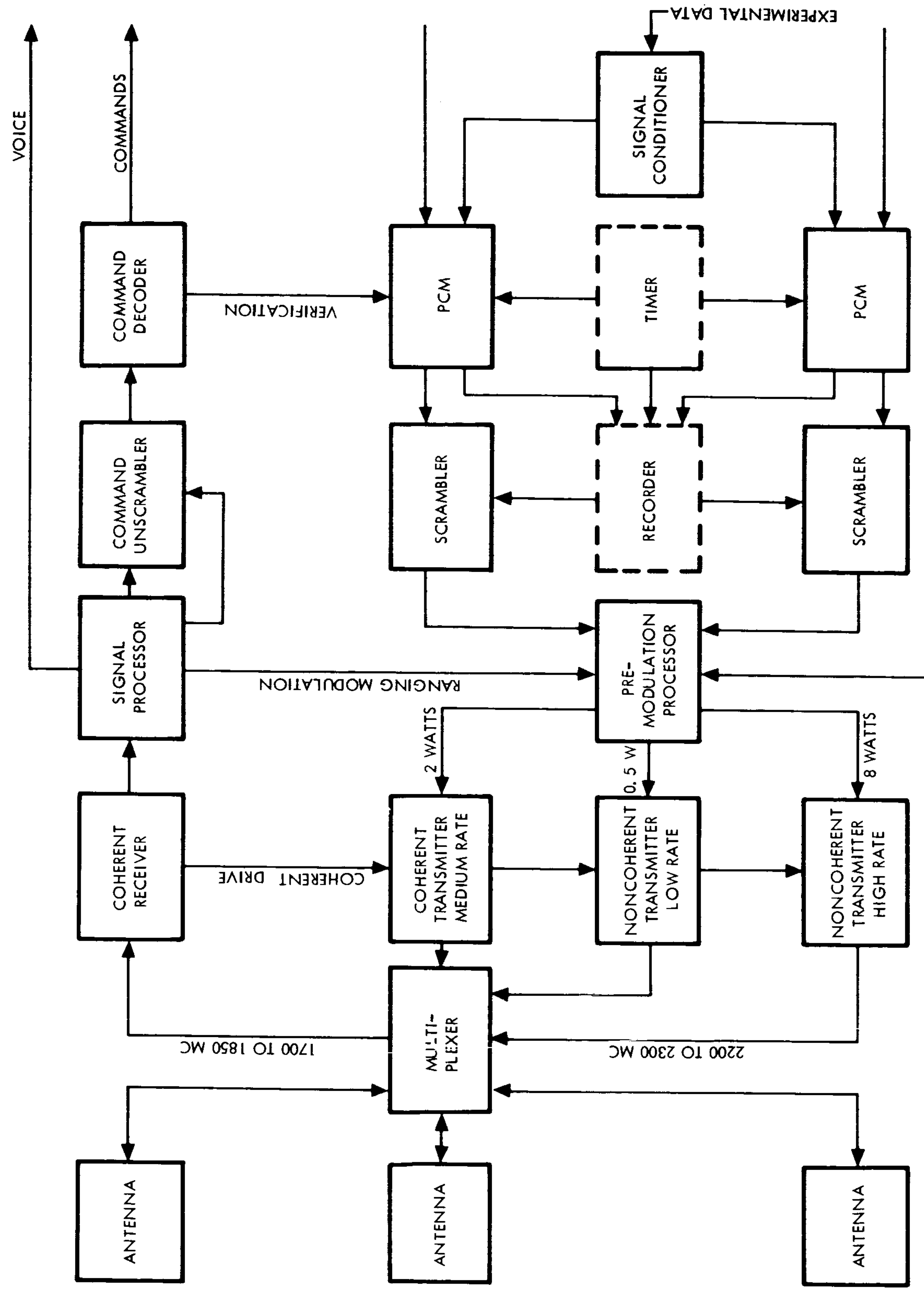

Figure 10. AF Communications/Data System

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For the most part, the Air Force experiments do not impose rapid closed-loop data transfer operations, and a one-orbit period delay between receipt of down link data and response with up data commands is acceptable. In a few cases, where communications experiments are scheduled to operate in real time, more rapid response may be necessary. These cases cannot be accurately identified until a better picture of the Air Force ground network provisions is available.

NASA ground stations can accept SGLS data rates and formats; however, these data could only be recorded.

EARTH LANDING SYSTEM

Previous analyses, as reported in SID 64-1860-20, showed that the pressure in the parachute compartment would fall below Apollo specifications after fourteen days.

An analysis was performed to determine the feasibility of sealing the recovery compartment to prevent outgassing of materials and to control the minimum recovery compartment internal pressure to a level equivalent to Apollo. It became apparent, however, that total sealing of the recovery system compartment was unfeasible from a structural standpoint. The forward heat shield, as presently designed, is structurally limited to a differential burst pressure of 2 psi. Therefore, to consider sealing above this differential pressure level would require complete structural design. Even partial sealing of the recovery compartment above the level that presently exists would require a major design effort. Based on the structural analysis performed, it was conservatively estimated that the maximum leakage area out of the recovery compartment is 22.6 square inches, which is equivalent to 146 square centimeters.

In earth orbits, the external ambient pressure will be so low that it can be considered to be zero for all practical purposes. Under these conditions, the internal pressure of the compartment will be controlled by the leak rate out of the recovery compartment and the vapor pressure at which the materials inside the compartment will sublime. Based on the existing leakage area and the estimated free air volume, it has been calculated that the recovery compartment will be completely evacuated to the external ambient pressure in a very short time if outgassing is not considered. Therefore, it is necessary to consider the outgassing phenomenom to maintain the compartment pressure level at a preselected value.

The pressure level inside the compartment can be maintained at a predetermined level by permitting outgassing from material coatings, lubricants, etc., or by the addition of a subliming or vaporizing substance whose vapor pressure and outgassing characteristics are determined by the temperature and ambient pressure. This is shown in Figure 11. Because the leakage area of the compartment is known, and the vapor pressures of different materials are relatively well established, the mass flow required to maintain a desired pressure level for any sublimating material over a specified time period can be calculated. It was found that by introducing approximately 10

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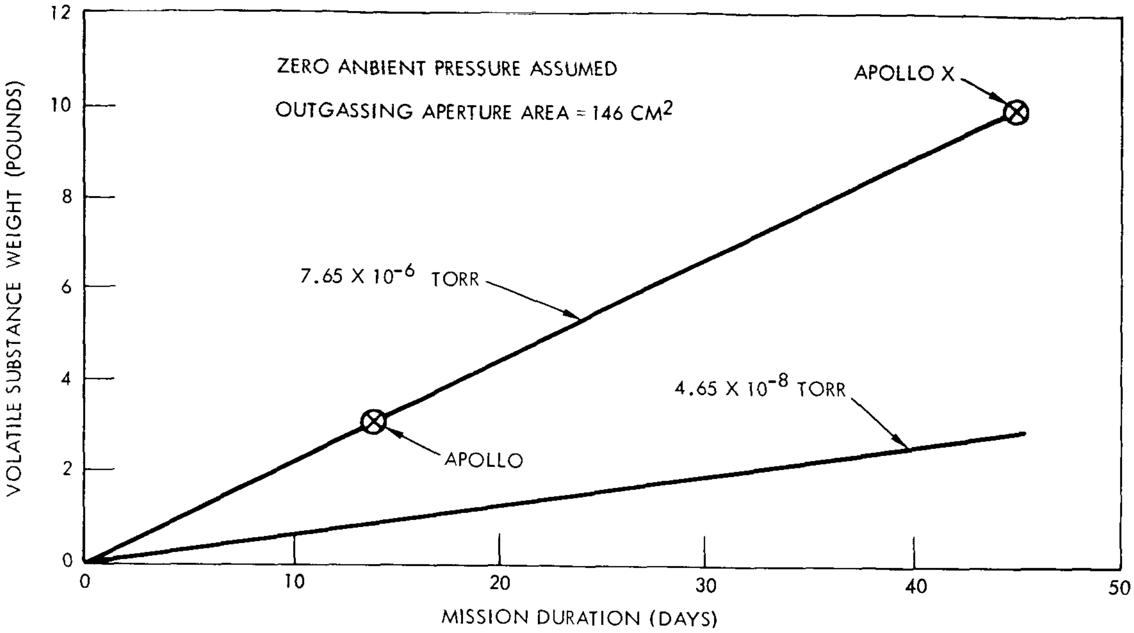

Figure 11. Parachute Compartment Pressure

pounds of polysiloxane, which is one of the lubricants used in the recovery system compartment, a pressure level of 7.5 x 10^{-6} Torr could be maintained for a leakage area of 146 square centimeters for 45 days. This pressure level is equivalent to the vacuum level specified for the Apollo recovery compartment. Therefore, it can be concluded that the pressure level of the recovery compartment can be maintained at the 10^{-6} Torr level simply by the addition of a small amount of a sublimating substance without any structural modifications required.

Thermal analyses were also performed to determine the temperature in the parachute compartment. Figure 12 illustrates the points at which the temperatures were measured assuming values for the outside, insulation, and parachute packing cover materials. For the Apollo emissivities, the temperatures at the parachutes (T_1, T_2, T_3, T_4) are below the Apollo specification temperature of -65 F. Table 18 summarizes for all orbits the variation in these temperatures as these emissivities and the transfer coefficients are varied. Line three of the table shows that by changing the insulation, the parachute packing covers and the outside coating, a satisfactory set of temperatures can be obtained.

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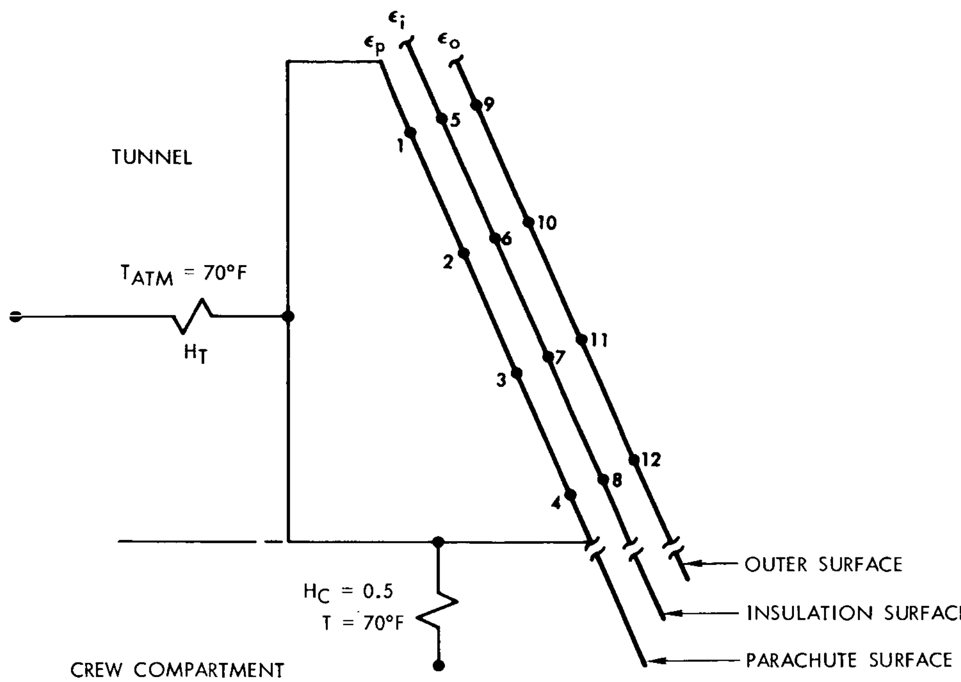

Figure 12. Thermal Network for Earth Landing System Analysis

Table 18. Parachute Compartment Temperatures—All Orbits

k_{PARA} (Btu/hr-ft-°F)	k_{INSUL} (Btu/hr-ft-°F)	h_{TUN} (Btu/hr-ft^2-°F)	Emissivity			Steady State Temperatures (F)											
			ϵ_p	ϵ_i	ϵ_o	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
0.08	0.01	0.5	0.7	0.7	0.25	-88	-116	-116	-87	-126	-138	-138	-127	-143	-148	-148	-144
0.08	0.01	0.5	0.7	0.06	0.25	-46	-82	-81	-45	-155	-162	-162	-156	-167	-170	-170	-168
0.08	0.01	0.5	0.06	0.06	0.25	-16	-51	-50	-15	-177	-181	-181	-178	-186	-188	-188	-187
0.08	0.01	0	0.7	0.7	0.25	-163	-170	-155	-109	-181	-182	-172	-152	-188	-186	-178	-168

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ENVIRONMENTAL CONTROL SYSTEM

As specified by NASA, a single gas O_2 atmosphere was used and the thermal control system for the external device is independent of the thermal control loop of the CSM. The studies of the environmental control system were divided between thermal analyses and the ECS equipment.

THERMAL ANALYSIS

The purpose of the thermal analysis studies was to establish the vehicle heat balance and define thermal loads so that the temperature control system could be properly designed. The thermal loads acting on a space vehicle are classed as either external or internal. External loads arise from direct solar energy, solar energy reflected from the Earth, and direct thermal energy from the planetary body as a result of its surface temperature. Internal heat loads consist of metabolic heat from the crew and waste heat from all power-consuming equipment, such as electronic gear and electric motors. A separate heat balance was determined for both the command module and rack.

External heat loads for each module were determined (using a computer program) for all the orbit low inclinations. The computer program yielded thermal environments and temperature histories and gave the total net heat flow into or out of the module and the external and internal wall temperatures.

Figure 13 shows the command module heat loss as a function of time. It is seen that for all orbits the heat loss is greater than about 850 Btu per hour. This means that the SM radiators will not be overtaxed, and that some of the hot glycol can be routed through the cabin heat exchanger to warm the cabin.

Similar analyses were performed for the rack and are shown in Figure 14. The heat loss from the airlock and the total rack heat loss are shown. A Configuration D rack is shown, since the radiated fuel cell heat presents the worst case (the fuel cells, of course, have their own thermal control loop with radiators). No experimental or metabolic heat is included in these curves. By varying the insulation (K/χ) and the rack exterior coatings, the total rack heat loss can be reduced to about 2000 Btu per hour (750 Btu per hour for the airlock). The addition of metabolic heat and experimental heat loads would reduce the heat loss to zero or a negative value. It appears that a thermal loop using radiators similar to that of the CSM is adequate.

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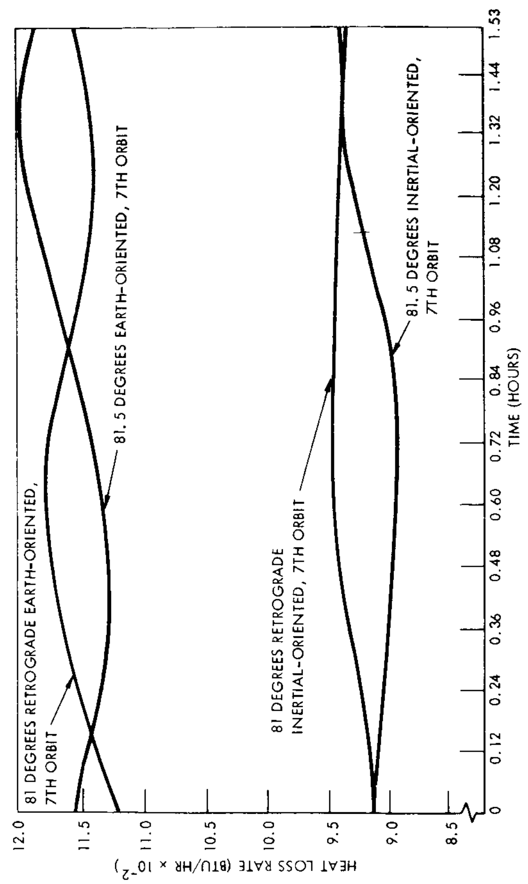

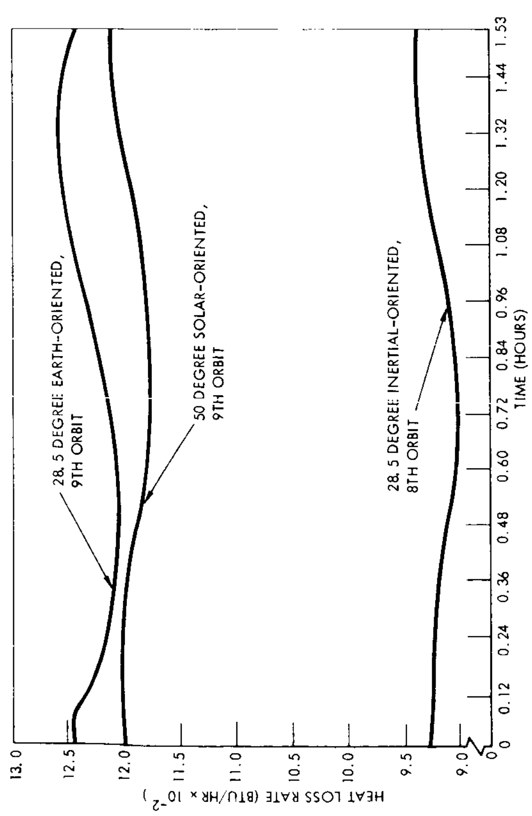

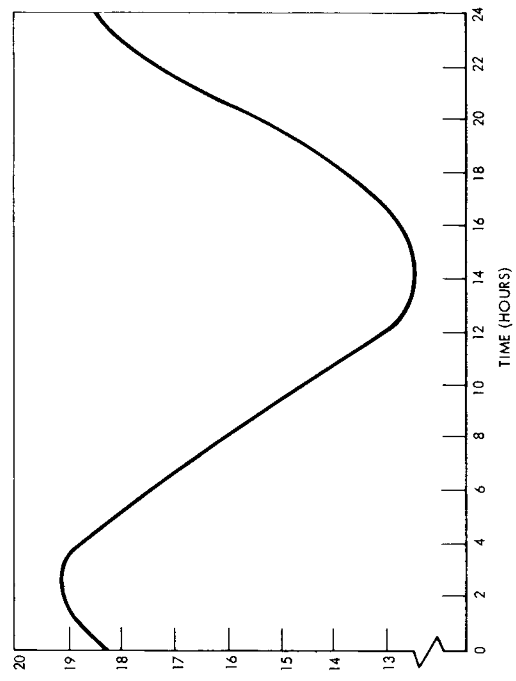

Figure 13. CM Heat Loss

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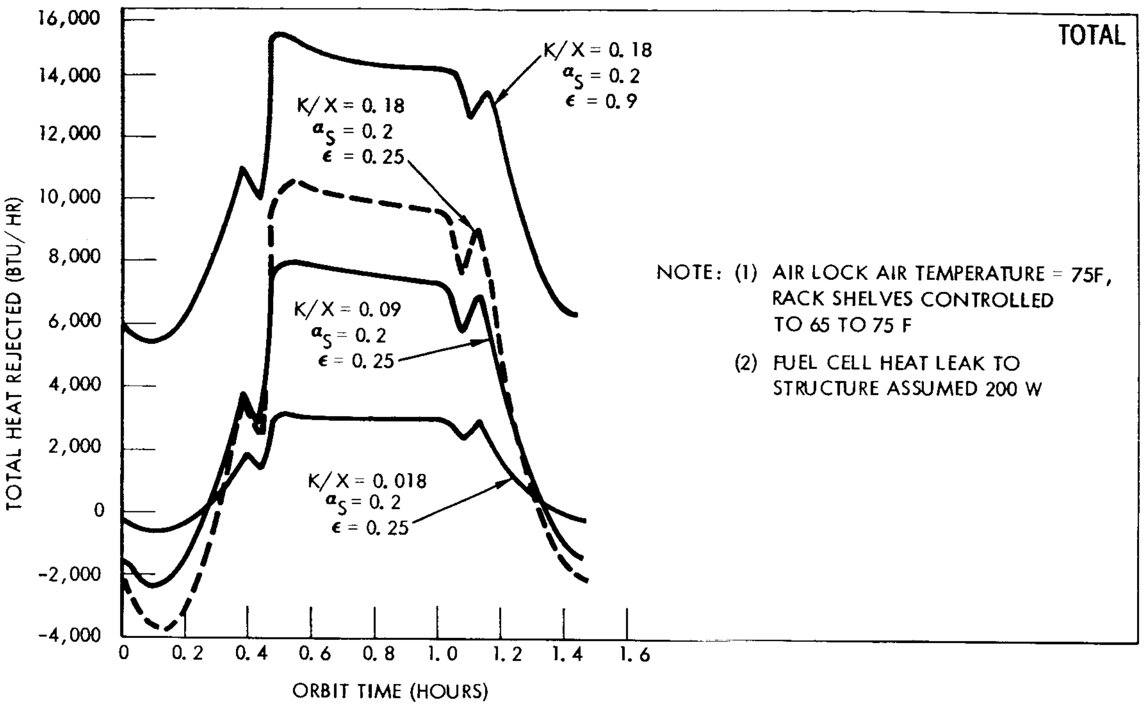

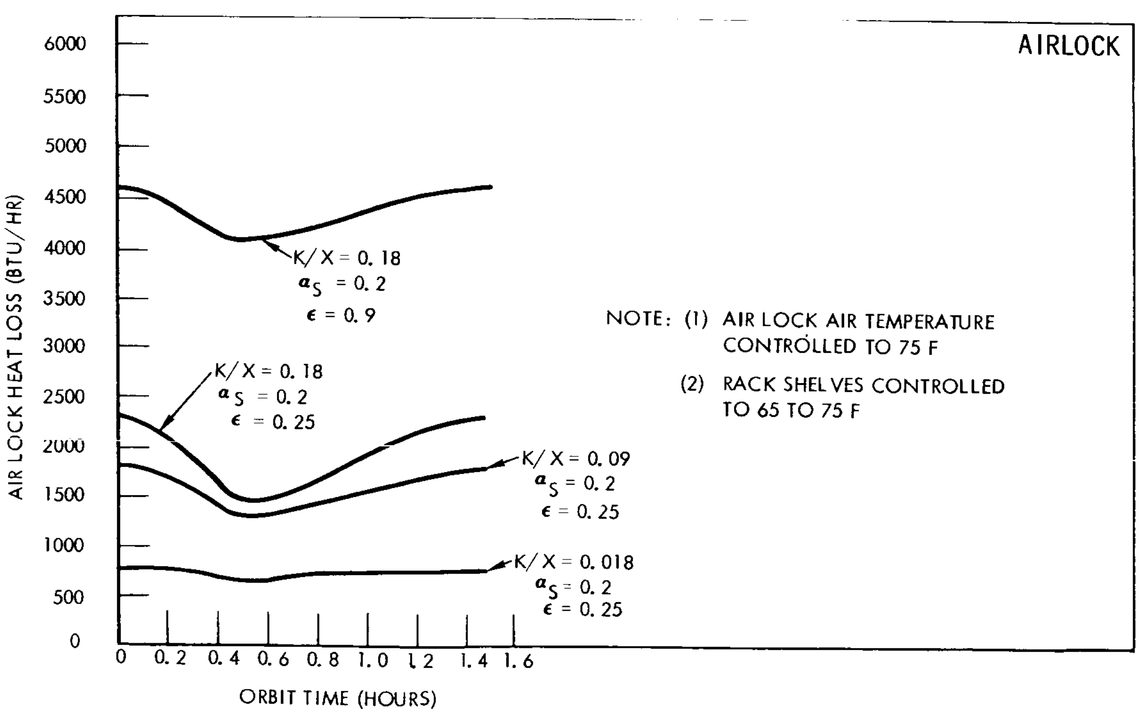

Figure 14. Rack Heat Loss

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ECS SPACECRAFT EQUIPMENT

The ECS equipment required for the various configurations have slight differences. Figure 15 shows the equipment for Configuration 1. On the right is the basic Apollo ECS. It is noted that Apollo has an interface with the LEM that involves a water line and an O_2 line for pressurizing the LEM.

For Configuration 1, a retractable duct is installed in the CM tunnel area together with a blower to force air from the CM into the external device. The rack contains a thermal control loop and the airlock has a depressurization valve and pressure controllers. To remove contaminants, a compressor loop with a catalytic burner is included.

To repressurize the airlock, high pressure O_2 is carried. The SM cryogenic tanks can supply about two repressurizations.

To extend the ECS system life to the 30 or 45 days required for configurations D', D, and C, some components must be spared or made redundant.

Life extension analyses showed that some components, due to accessibility problems, could be added only as built-in redundancy while others

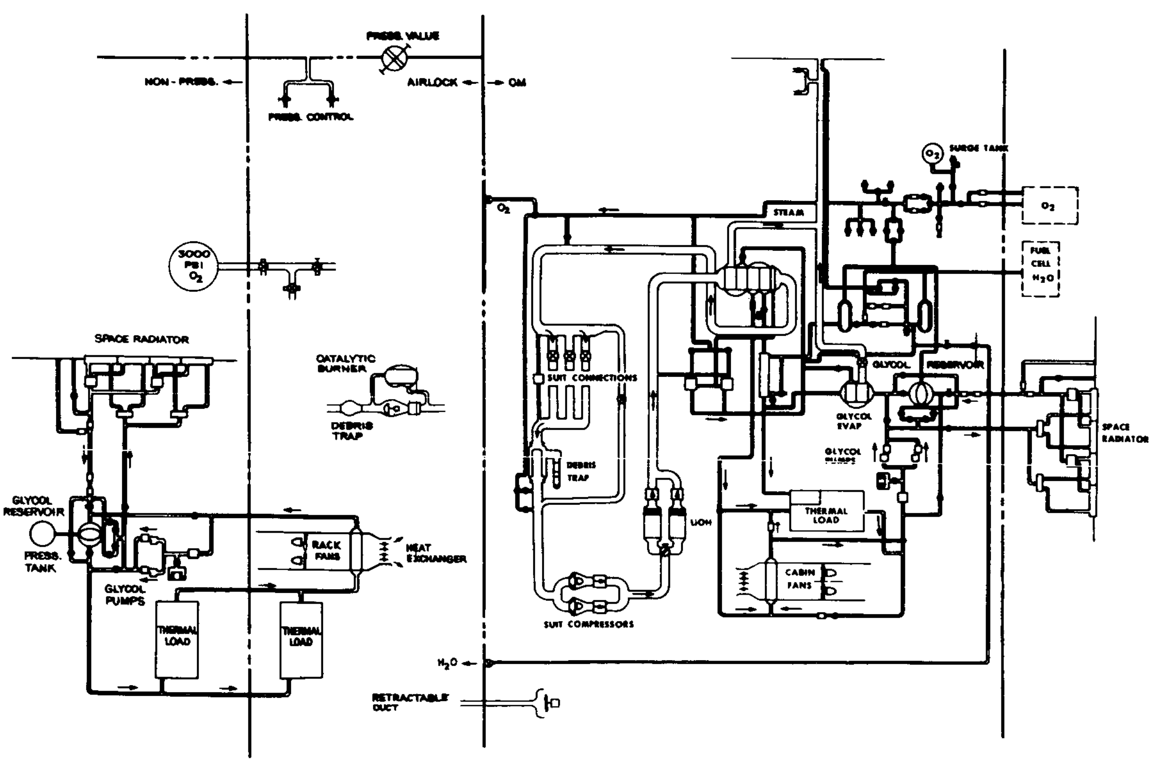

Figure 15. Environmental Control System—Configuration 1

could be installed as spares. The built-in redundancy items include the water check valve, water tank pressure relief valve, glycol evaporator water control valve, suit compression check valve, glycol temperature control valve, and glycol control valve. A redundant suit compressor would be required or the suit compressor bearings would be redesigned to achieve the desired operatine life. The cabin blower and the oxygen partial pressure sensor are additional components added as spares.

Configuration D' modifies the Configuration 1 system by adding three cryogenic Block II O_2 tanks and a loop involving pressure reduction to 100 psi to the external device. The 100 psi O_2 is piped to the CM ECS system; 100 psi is required by the CM system to pressurize the water tank (20 psi) and the glycol reservoir and glycol evaporator (100 psi). For this configuration, the SM O_2 supply is used until it is exhausted (approximately 10-14 days), then the O_2 in the external device is used for the remainder of the mission.

The problems of storing cryogenics on the external device for 10-14 days, together with the boiloff and venting problems, are treated in a later section.

CRYOGENIC STORAGE SYSTEM

One of the principal factors presently limiting the Apollo mission duration is the capacity of the cryogenic storage system. The Apollo Block II tank size is adequate for a mission duration of 10 to 14 days by reducing electrical loads.

The design, fabrication, and testing of a cryogenic hydrogen or oxygen tank generally are valid only for one size. Any significant change results in a major redesign and test program, and in some cases requires new tooling. An Apollo extended mission requires a new tank design.

Configuration 1 uses the Apollo SM tankage without change resulting in a nominal mission of 14 days. Additional power requirements can be met by the addition of batteries in the external device. Metabolic, leakage, and repressurization O_2 could be supplied by the high pressure gas storage system.

Apollo X tanks were designed to achieve a mission duration of nominally 45 days. This was achieved by increasing the tank size. Table 19 summarizes the characteristics of these large tanks and compares them with Block II tanks.

Configuration C uses the large tanks installed in sectors 1 and 4 of the SM. In Configuration D, these tanks are installed on the external device only with Block II Tanks in the SM. Configuration D' requires the use of multiples of Block II tanks. Analyses revealed that four H_2 and three O_2 Block II tanks sufficed in the external device with a Block II SM. Configuration D and D' present certain problems. The cryogenic tanks on the external device are not used for the first 10-14 days. Heat leaks into these tanks cause an increase in fluid volume and pressure. Unless this increase is relieved, the tanks will rupture. Therefore, this fluid must be used or the boiloff vented overboard. The O_2 tank problem can be solved by using these tanks for repressurization of the airlock or for leakage or metabolic use. The H_2 tanks are used only for the fuel cells and represent the worst boil-off and insulation problems. Also consistent with Apollo design, there is no overboard vent system. The existing vent line in the cryogenic storage system is used only on the pad for loading and cooldown. These valves are then sealed shut before boost. This philosophy was adopted by Apollo for reliability reasons. Overboard venting would require a valve that opens and closes many times. If this valve failed to close all cryogenic fluid would be lost.

Table 19. Block II and Apollo Cryogenic Tanks

Characteristics	Block II		Apollo X	
	Hydrogen	Oxygen	Hydrogen	Oxygen
Operating pressure (psia)	250	900	250	900
Burst pressure (psia)	450	1530	450	1530
Usable fluid (lb/tank)	28	320	102.5	1198.5
Total fluid (lb/tank)	29.12	326.4	104.5	1210.5
Number of tanks	2	2	2	2
Heat leak (Btu/hr)	8.01	19.3	9.5	31.0
	(130 F)		(150 F)	
Dry weight (lb)	178.4	179.4	343	505
Wet weight (lb)	236.64	832.2	552	2926
Pressure vessel				
Size (inches)	28.3 Sphere	25.1 Sphere	36.3 dia 53.6 long	36.4 dia 41.7 long
Outer shell				
Size (inches)	31.8 Sphere	26.5 Sphere	40.3 dia 57.7 long	40.3 dia 45.6 long

To solve this imbroglio for configurations D and D', several solutions are possible. First, the external device tanks could be off-loaded, allowing volume for fluid expansion. Second, the fluid could be vented through the fuel cell purge valves. These valves already exist but require manual operation. Third, the Apollo philosophy could be modified to allow the installation of a venting system.

Figure 16 illustrates the technique of off-loading the tanks. Only one Apollo X tank is shown, so the scale would be consistent with that of four Block II H_2 tanks for Configuration D'. For Apollo X tanks, assuming a heat leak of 9.5 Btu/per hour, off-loading to about 80 percent yields no venting requirement for 14 days. If the SM tanks are depleted in a shorter time, these tanks could be further loaded; for example, to 90 percent to prevent venting for ten days. Therefore, the solution for Configuration D is to

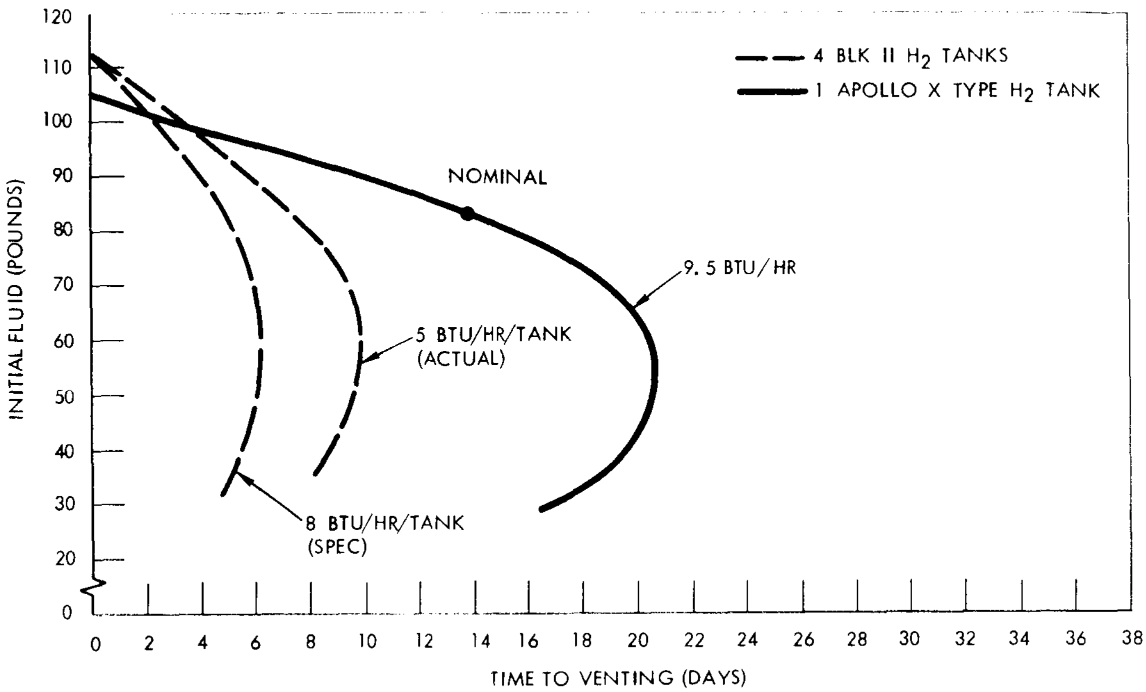

Figure 16. External Device CSS—Configurations D and D'

off-load the Apollo X H_2 tanks on the external device. The curves for Configuration D' show that for any off-loading no greater than 10 days before venting can be obtained. The two curves for the Block II tanks illustrate the specification heat leak and the actual heat leak being obtained by Apollo. However, with either heat leak, the off-loading technique does not solve the problem.

Therefore, some sort of venting system is required. It is recommended that the fuel cell purge valves be used to vent the fluid overboard. To achieve the 30 days' duration required for Configuration D', the time of depletion of the SM CSS must be treated as a variable. Figure 17 shows the mission duration as a function of initial tank fill. It is seen that 30 days can be reached if the tanks are completely filled and the SM CSS can last for 14 days.

It must be emphasized that the results of the analysis for Configuration D' are marginal. It was assured that the temperature of the fluid in the tanks is uniform. This could only be achieved by mixing the fluid via the fans; however, this would only increase the heat tank.

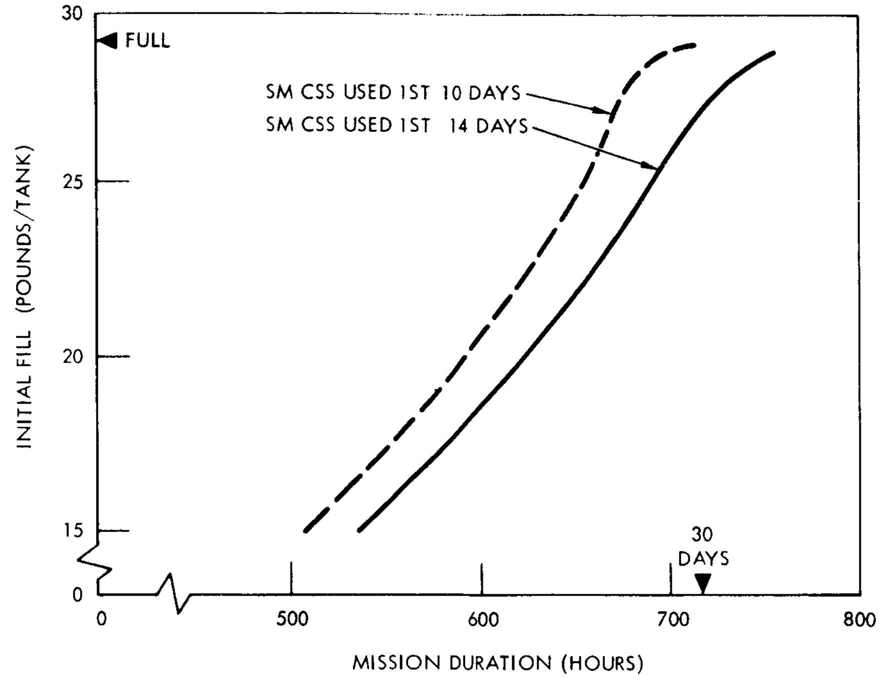

Figure 17. Cryogenic Storage—Configuration D'

The use of the external device fuel cells operating at the H_2 boiloff rate is another solution. This, however, would require more fuel cells and higher weight for the external device.

POWER SYSTEM

The power system analyses considered the energy requirements for each flight and determined the power system for each configuration. This section treats the power loads and energy requirements by flight and then summarizes the recommended power system for each configuration.

The energy requirements for the flights is summarized in Table 20. The housekeeping or vehicle loads are separated from the experimental loads. The experimental loads were determined by summing the power requirements for each experiment multiplied by the number of times the experiment is performed. Such an approach is conservative in that the use time of some subsystems is duplicated. For example, two experiments may require the use of G&N. These could perhaps be scheduled together. The results in Table 20, however, assume that the experiments are performed independently of each other.

One particular flight, Flight 215, was scheduled and its power requirements analyzed. The power load on the third day, as a typical example, is shown in Figure 18. It is seen that the "housekeeping" loads for this mission are essentially constant at 1440 watts. The variable housekeeping loads are data transmission, cryogenic storage system heaters, full use of all lights

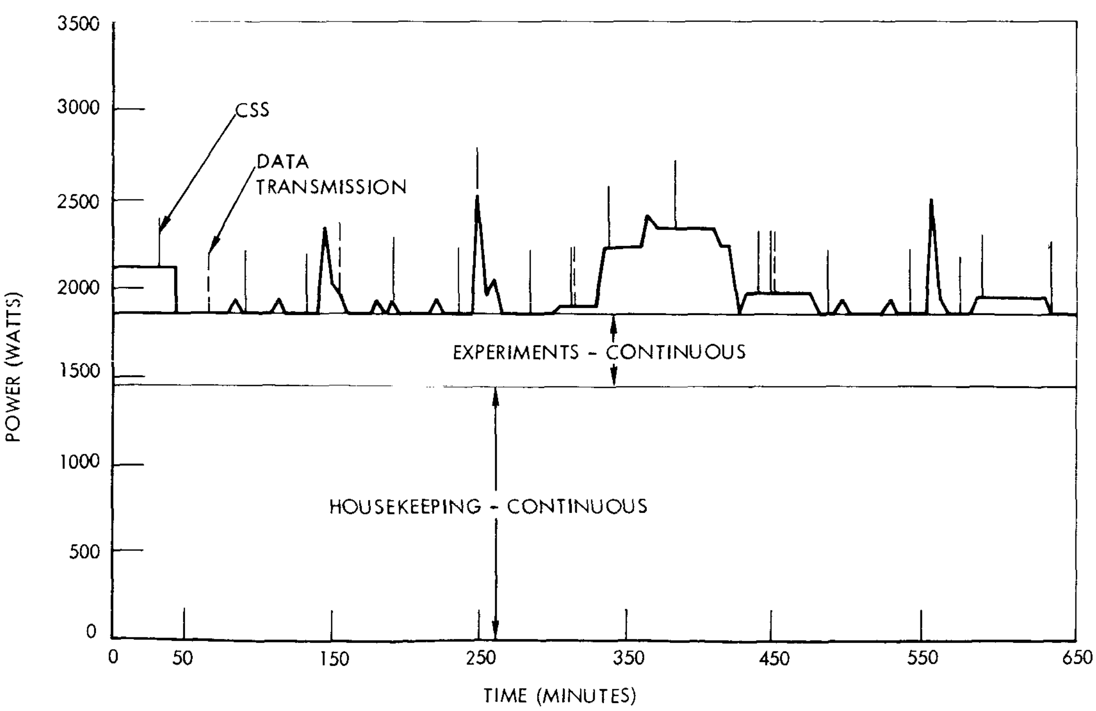

Figure 18. Integrated Power Load Profile — Flight 215, Day 3

Table 20. Energy Requirements Summary

Flight	Configuration	Vehicle Loads (kwh)	Experiment Loads (kwh)	Total (kwh)	Vehicle Capabilities (kwh)	Mission Duration Limit (days)	Battery* for Full Mission	Remarks
209	1	524	164	688	620	12.3	6	
507	1	530	149	679	620	12.8	5	
509	1	535	106	641	620	13.5	2	See Note (1)
215	1	524	242	766	620	11.3	12	
513	1	530	198	728	620	11.9	9	
211	D'	1102	256	1358	1540	30		(2)
219	C	1512	966	2478	2440	44.0		(3)
	D	1555	966	2521	2638	45		(4)
221	C	1518	492	2010	2440	45		
	D	1561	492	2053	2450	45		
518	C	1518	748	2266	2440	45		
	D	1561	748	2309	2450	45		
229	C	1512	891	2403	2440	45		
	D	1555	891	2446	2450	45		
230	C	1512	856	2368	2440	45		
	D	1555	856	2411	2450	45		
AF-1	C	1512	499	2011	2440	45		
	D	1555	499	2054	2450	45		
AF-2	C	1512	308	1820	2440	45		
	D	1555	308	1863	2450	45		

*450 AMP-HR EA

NOTES:
(1) Need battery or extra EPS fuel in SM for return
(2) Assumes Block II cryogenic system OK
(3) 45 days obtained with high pressure loading of H_2 tank
(4) Use rate depletes SM tanks in 11.3 days so rack H_2 tanks loaded to 84 lb each without venting

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and controls, and minor, short-duration loads such as SPS engine firing, reaction jet valves, transients, etc. The experiment loads have a continuous element and a variable element. The continuous element (with distribution efficiency) amounts to 400 watts.

Computer analysis of the integrated experiments for Flight 215 indicated that the charging of G&N, SCS, data processing, displays, etc., to each experiment individually, and providing for the resulting total, results in a significant overdesign. By scheduling experiments so that these subsystems are providing for several experiments at once and by rejecting those experiments that cannot be scheduled on that run, the energy requirement is reduced considerably. The experiment energy for Flight 215, for example, was initially estimated to be 242 kwh but was reduced to 174 kwh by the computer scheduling.

Table 20 assumes that the total energy available in the Block II tanks is 620 kwh. This is based on high pressure loading, and that power is consumed in accord with the Apollo profile. The energy available for Configurations C and D is based on an average consumption rate of 1850 watts and does not assume high pressure loading. Analysis of the power profiles for Flight 215 showed that consuming power at this profile, rather than the Apollo profile, produced about 623 kwh, which is not significantly different from the assumed 620 kwh.

Table 20 shows that supplementary power is required for all Configuration 1 flights, or the flight duration must be reduced. The number of batteries of 450 amp-hours (similar to those proposed in SID 65-226) required is also listed. Each battery weighs about 120 pounds. Flight 509 is synchronous orbital, and the return trajectory involves a six-hour coast period. Therefore, the CM entry batteries must be supplemented. Flight 219 C energy is also marginal. If high pressure loading is used, the 38 kwh deficit for this flight is easily made up.

Figure 18 also shows that the typical power loads vary between 1400 and 2100 watts. The power load can be handled by two fuel cells. Therefore, for Configurations C and D, when the SM power supply is operating, and for Configurations D and D', when the external device power system is operating, only two fuel cells operating at one time are required for mission success.

The Block II power system uses three fuel cells that operate continuously from countdown. Therefore, Configuration 1 uses the three fuel cells in the SM operating continuously or to the depletion of cryogenic H_2. This configuration is shown in Figure 19.

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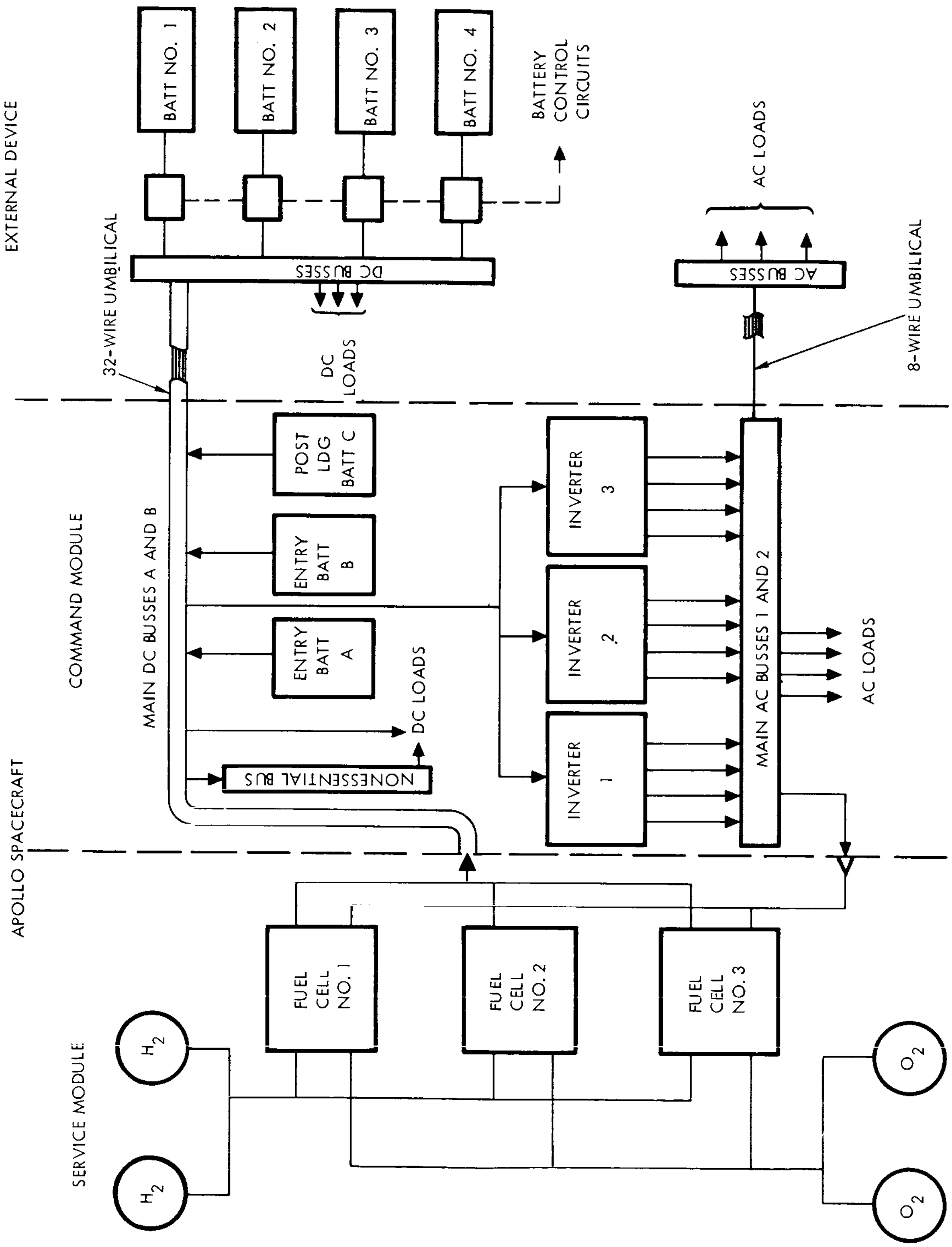

Figure 19. Power System—Configuration 1

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Power is supplied to the external device via two umbilicals. The dc umbilical is already in the CM to supply power to the LEM. An ac umbilical has been added. The external device will have dc and ac busses. The batteries for power makeup are also illustrated. In addition, secondary batteries for peak loads are included.

Configuration C uses fuel cells in the SM for the total mission. Reliability analyses showed that four 1,000-hour fuel cell stacks are required. Two of these operate from countdown. As these fail, the other two fuel cells are started. In-space start is required for these two fuel cells as well. For this purpose, secondary batteries are included.

Figure 20 shows the changes to the SM. The Configuration C external device power system deletes the primary batteries for power makeup (shown in configuration 10 but retains the peak load batteries.

Configurations D and D' are similar to Configuration 1 for the first 10 to 14 days of the mission; that is, the three fuel cells in the SM operate from countdown. After this period, the fuel cells on the external device are started. Three 1,000-hour cells on the external device are required for Configuration D, three 400-hour cells on the external device are required for Configuration D'.

The Configuration D system is shown in Figure 21. The power system to extend the mission duration, including fuel cells, cryogenic system and in-space start batteries similar to Configuration C, is in the external device. The ac and dc busses and the umbilicals are the same as Configuration 1.

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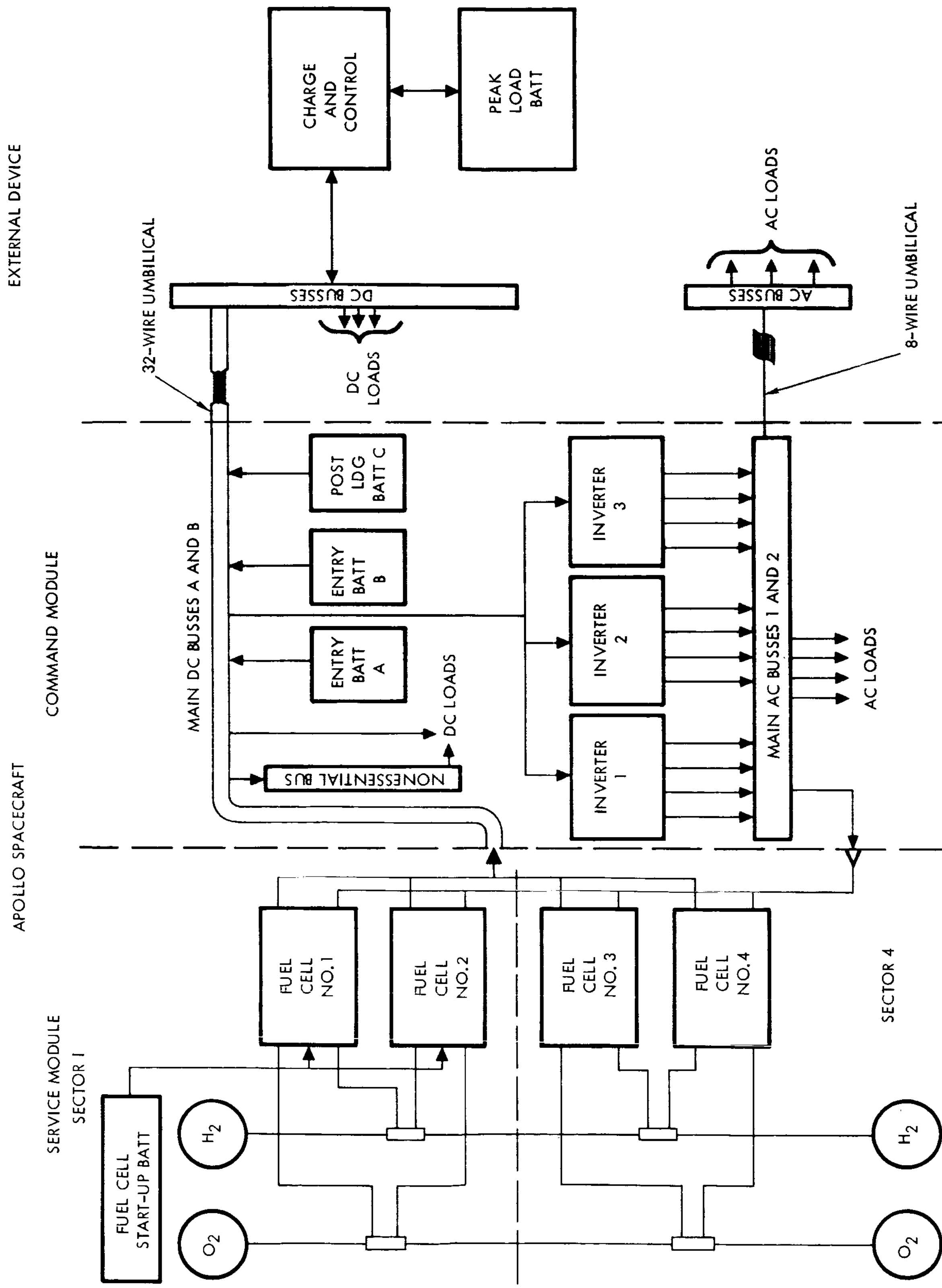

Figure 20. Power System—Configuration C

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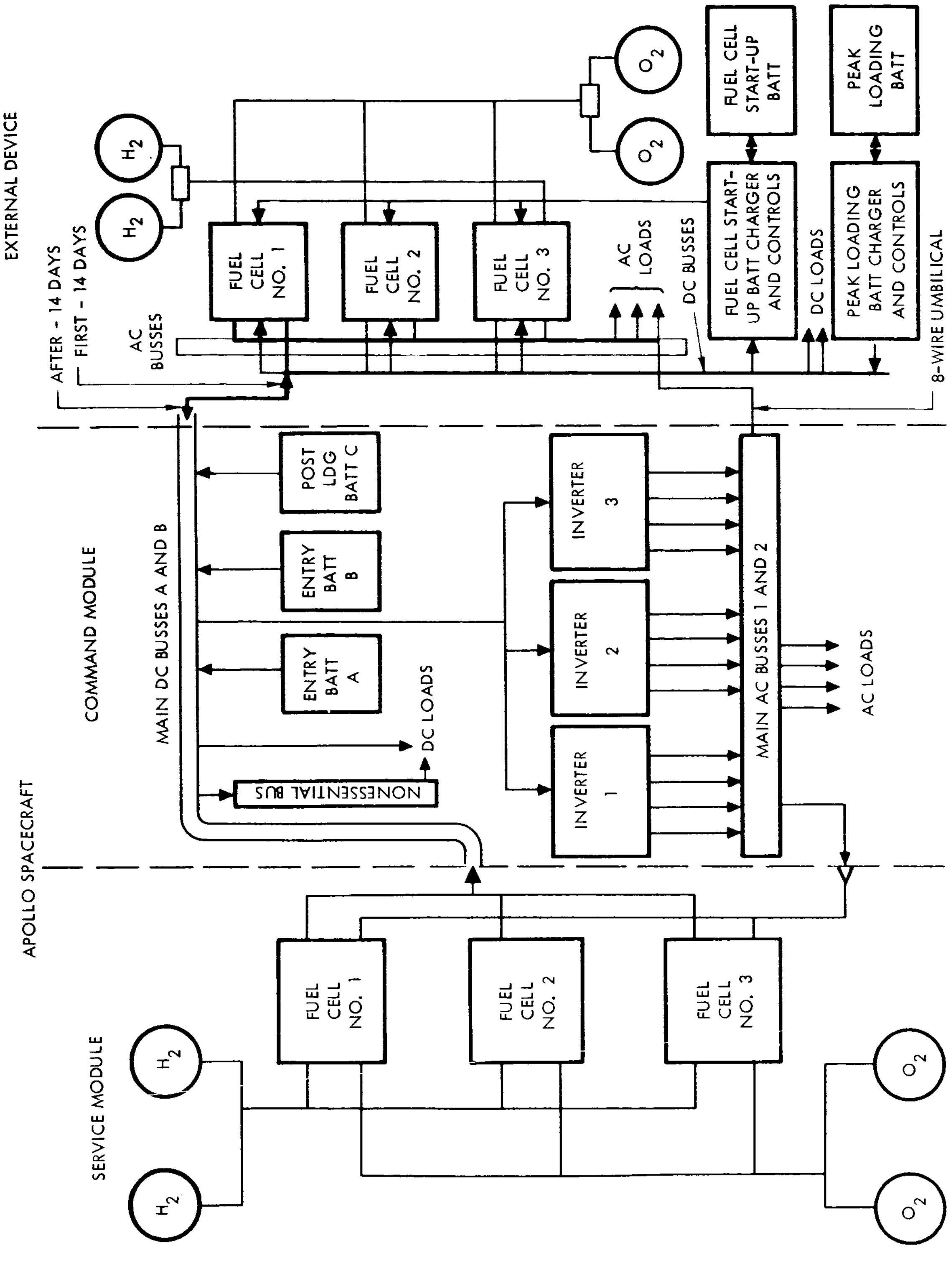

Figure 21. Power System—Configuration D

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GUIDANCE AND CONTROL

The capability of the guidance and control system to perform the NASA and AF flights was evaluated. The previous Apollo X study had established requirements for lunar polar orbit mapping. These demanded a local vertical hold to an accuracy of ± 0.5°, ± 0.02°/sec for approximately 82 hours. In the AES flights, some missions, particularly Flight 518, require local vertical hold to an accuracy of ± 0.1°, ± 0.01°/sec; such a deadband can only be attained with a modification to G&N system.

Table 21 shows the control capability of the Apollo Block II and Apollo X guidance and control systems. For Block II, the specification capability and that achievable with AES configurations is shown. Of course, the change in inertias results in a decrease in the minimum impulse. The attitude hold capability is not changed because such a change would involve a modification to the electronics.

Table 21. Control Capability

Mode	Block II		Apollo X	
	Specification	AES	AES	AES-Mod
G&N attitude hold	± 0.5° ± 0.05°/Sec	± 0.5° ± 0.05°/Sec	± 0.5° ± 0.05°/Sec	± 0.1° ± 0.01°/Sec
Minimum impulse	0.04°/Sec	0.02°/Sec	0.02°/Sec	0.02°/Sec
SCS attitude hold	0.2° ± 0.2°/Sec			± 0.2° ± 0.2°/Sec
G&N local vertical	± 0.5° ± 0.05°/Sec	± 0.5° ± 0.05°/Sec	± 0.5° ± 0.05°/Sec	± 0.1° ± 0.01°/Sec
SCS local vertical			± 0.5° ± 0.02°/Sec	± 0.5° ± 0.02°/Sec
G&N manual maneuver	± 0.5°/Sec			± 0.5°Sec
SCS manual maneuvers	To ± 5°/Sec or ± 0.5			To ± 5°/Sec or ± 0.5

Column 3 of the table shows the capability of the Apollo X system. A local vertical hold capability was added to the SCS by adding horizon scanners and modifying the SCS electronics. To achieve the AES requirements, the G&N electronics can be modified to obtain the deadband shown in column four.

Figure 22 summarizes the reliability of the G&C system for each AES flight. The Configuration 1 Flights 209 and 507-209 are restricted to the Block II system. Flight 507 presents the greatest reliability problem for G&N. This is due to the requirements for ± 35° local vertical hold, which in Block II can only be performed by the G&N. A simple modification to the SCS, the reintroduction of the Block I local vertical black box, could satisfy this requirement and not result in any significant reduction in SCS reliability.

For Configurations C and D flights, the reliabilities are for the systems designed for Apollo X. The AES program requires more use of the G&C system. The reliability of the G&C can be improved by more sparing and redundancy.

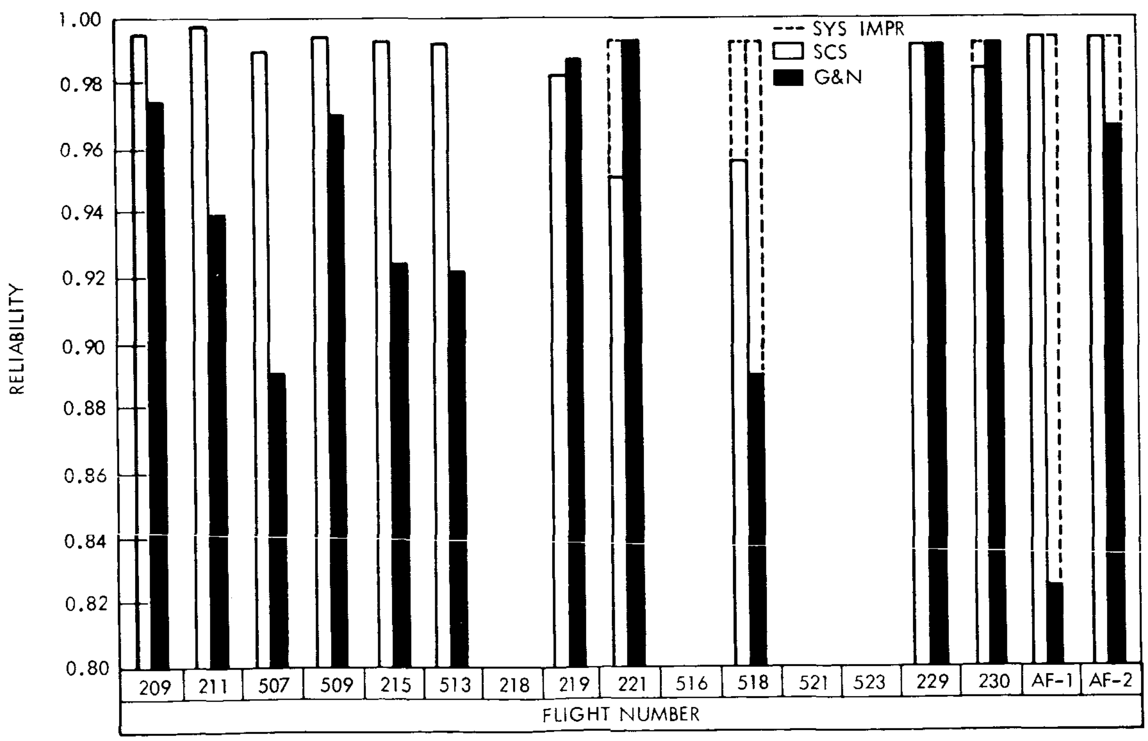

Figure 22. G&C Reliability

REACTION CONTROL SYSTEM

The reaction control system analyses considered the propellant requirements and engine starts for the various flights and the use of an RCS system on the external device.

Configurations 1 and D' were restricted to the use of the Block II propellant capacity; Configurations C and D could obtain a larger propellant capacity by use of LEM tankage in the SM.

Figure 23 shows the propellant used for each flight. Table 22 lists the exceptions to the experiments schedule because of tankage capacity. Experiments 0101-0102 require the rotation at various rates of the spacecraft about the Y and Z axes. As such, these are large propellant consumers. The targets of opportunity require rotation about the X axis to sight ground or space targets. The propellant required for such maneuvers is listed in Table 23.

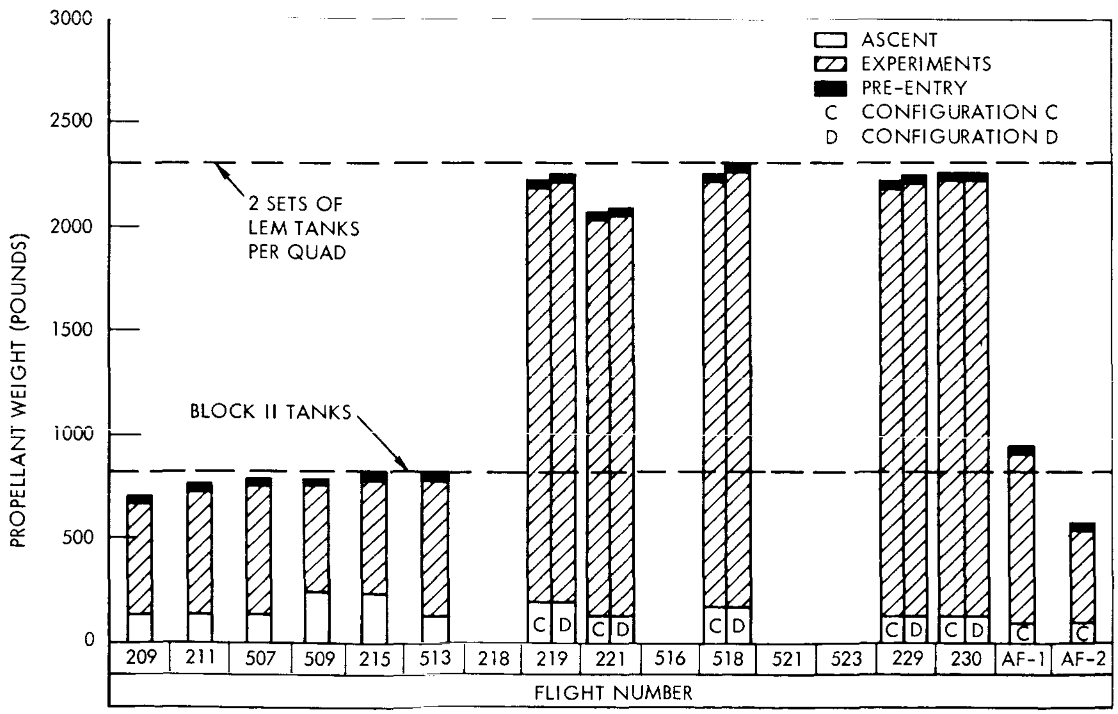

Figure 23. RCS Propellant Requirements

Table 22. Experiment Modifications—RCS Propellant

Flight Number	0101 - 0102 Rotation Required	0101 - 0102 Sequence Available	Targets of Opportunity	Comments
209	6	6	-	No changes necessary
211	12	5	84	
507	6	4	40	
509	4	3	23	
215	6	0	10	Artificial g test - 0.18g at 50 ft (3.3 rpm)
513	6	0	196	
219C	19	15	80	
219D	19	12	80	
221C	-	-	-	No changes necessary
221D	-	-	-	No changes necessary
518C	19	0	-	Run 0802B 213 times (scheduled as 270)
518D	19	0	-	Run 0802B 154 times (scheduled as 270)
229C	19	15	24	
229D	19	12	24	
230C	19	18	13	
230D	19	12	13	
AF-1	-	-	-	No changes necessary
AF-2	-	-	-	No changes necessary

Table 23. Propellant Consumption for Spin-up and Targets of Opportunity

Flight Number	Propellant per Spin-up (lb)	Propellant per Target (lb)
209	79	-
211	88	0.16
507	88	2.1
509	131	1.6
215	103	2.2
513	86	1.4
219C	96	1.9
219D	125	2.4
221C	-	-
221D	-	-
518C	109	-
518D	135	-
229C	99	2.0
229D	126	2.4
230C	94	1.8
230D	124	2.4
AF-1	-	-
AF-2	-	-

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For Flight 215, only 5 of the 12 required operations for experiments 0101-0102 can be performed. The propellant used by the 84 targets of opportunity could not change this situation on this flight. All other experimental objectives were accomplished. For all flights where 0101-0102 experiments are required, except for Flight 209, the number of available operations is less than required. Flight 518 did not have sufficient propellant to perform experiments 0802B (Radiometrics and infrared Earth mapping) the required number of times. Finally, on Flight 215 the checkout of the artificial-g experiment had only enough propellant to accomplish 0. 18 g.

Figure 24 summarizes the jet starts for each flight. The only flight that exceeds the Apollo specification is 518. This is due to the tight deadband requirements of ±0. 1. Although this flight exceeds the specification, several flights are as large as 7500 starts.

As indicated in the previous discussion, the quantities of RCS propellant limit the permissible experiment cycles. A way to alleviate the available RCS propellant restriction is to put an RCS system on the external device. One approach would make this system independent of the CM—SCS and G&N. In such a case, some form of guidance and control is required in the external device. In addition, an instrumentation and control/display panel similar to that in the CSM is also required. The combination of these would involve a weight penalty of 200-500 pounds in addition to the RCS system weight.

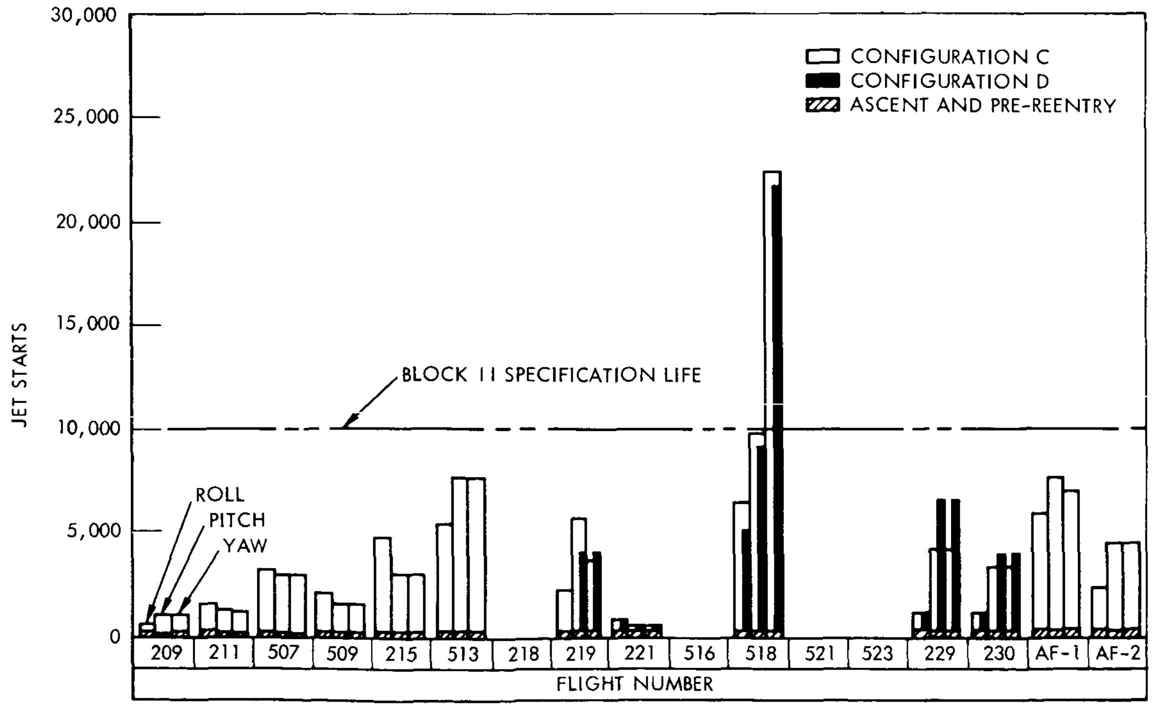

Figure 24. RCS Jet Starts

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The other approach is to permit the external device RCS to be operated from the CM. This would require considerable interfaces. The Master Caution indicators on the CM control panel provide visual indication of a malfunction or impending malfunction. The present SM RCS panel cannot be modified without major alterations. Space is not available on the panel for the required additional displays. An additional panel must be installed in the CM.

To operate the LEM RCS through the CSM SCS logic, the docking mechanism must be modified to permit rotating the LEM 45 degrees. The rotation provides alignment of the LEM RCS and SM RCS along the Y and Z axes. The LEM RCS solenoid valve electrical harness must be routed through the tunnel and interfaced with the SM RCS/SCS logic or, alternatively, provide an additional black box in the external device to convert the signal logic to a form suitable for the external device RCS Configuration. This will require a new hardware item but will eliminate the other modifications.

[redacted]

SERVICE PROPULSION SYSTEM

The service propulsion system requirements are dictated by the boost and deorbit requirements and the experiment requirements. The ground rules specified the use of the Block II system on Configurations 1, D, and D'. In Configuration C, the propellant tanks could be changed. For all configurations, mission durations in excess of 14 days require design proof testing of the main engine to verify analytic results.

Figure 25 shows the propellant requirements for the flights. The experimental requirements, except for Flight 513, are for Experiment 0102, which requires a linear acceleration. This is accomplished by firing the main engine for 10 seconds. Each operation consumes 700 pounds of propellant. This experiment is performed by firing the engine 90 degrees to the velocity reactor and alternating from ±90 degrees. Flight 513 carries propellant for rendezvous with Echo II.

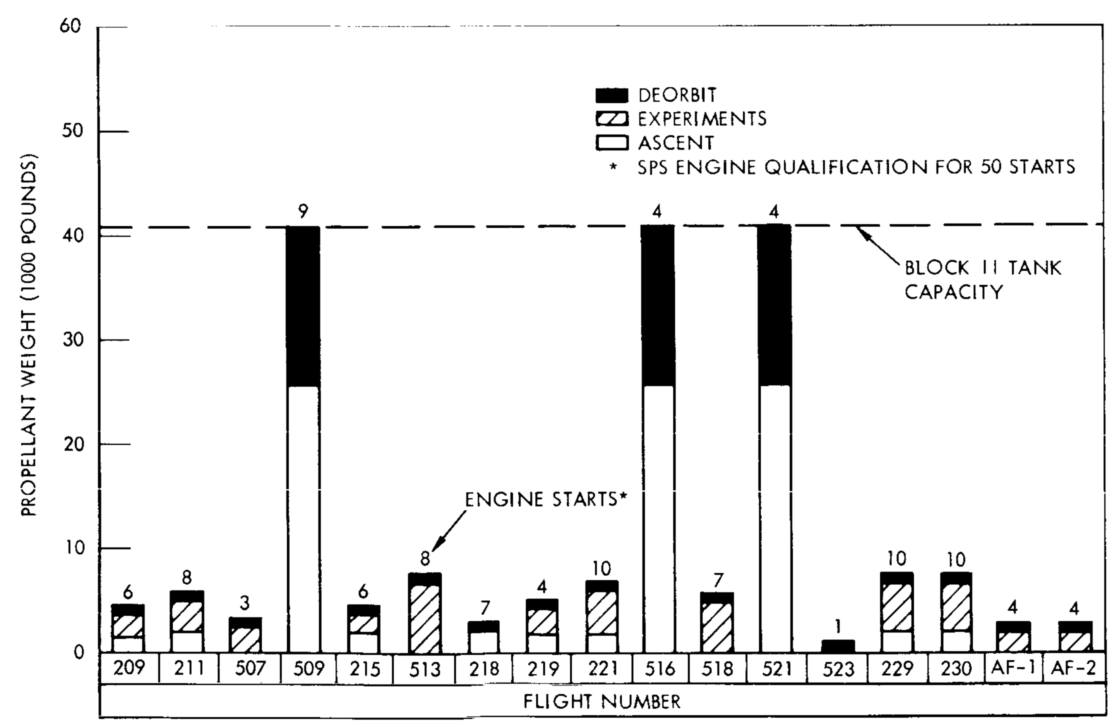

Figure 25. SPS Propellant Requirements

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[redacted]

Figure 25 also shows that except for Flights 509, 516, and 521, the Block II tanks are not required. Previous Apollo X studies recommended tanks that carry 7500 pounds of propellant. Because the experiment requirements have increased, these are marginally adequate. It is recommended that tanks of 10,000-pound capacity be used on Configuration C. Based on the ground rules, Configurations 1, D, and D' must use Block II tanks.

SUBSYSTEMS INSTRUMENTATION

Attendant to the addition of subsystems such as fuel cells, cryogenics, ECS hardware, etc., to the external devices in Configurations D and D' is the problem of monitoring and control. Table 24 compares the installation of this monitoring and control in the CM or in the external device. If the instrumentation is in the CM, a large number of wires in several umbilicals is required, along with major modification to the CM display panel. Therefore, consistent with the desire for minimum modification, the displays and controls are located in the external device. Some master caution and warning indicators are still required in the CM.

Table 24. Subsystem Instrumentation—External Device

		Monitor and Control in CM	Monitor and Control in External Device
Monitor Umbilical	Configuration D	80-22 GA (twisted-shielded pairs) 12-22 GA (shielded bundle)	6-22 GA wires (shielded bundle)
	Configuration D'	92-22 GA (twisted-shielded pairs) 12-22 GA (shielded bundle)	
Control Umbilical		36-22 GA wires 23-20 GA wires	None
Power distribution umbilical		32-12 GA wires 8-16 GA wires	32-12 GA wires 8-16 GA wires
Other		Major modification to CM control and display panel	New panel

Figure 26 shows the control panel that must be installed in the external device for Configurations D and D'. Since batteries were used for in-space start of fuel cells, the controls for these are shown as an alternate; the displays for a catalytic reactor in-space start system are also shown.

Since Configurations 1 and C do not require fuel cells and cryogenics in the external device, the control panel requirements can be reduced to that shown in Figure 27 but redesigned for optimum layout.

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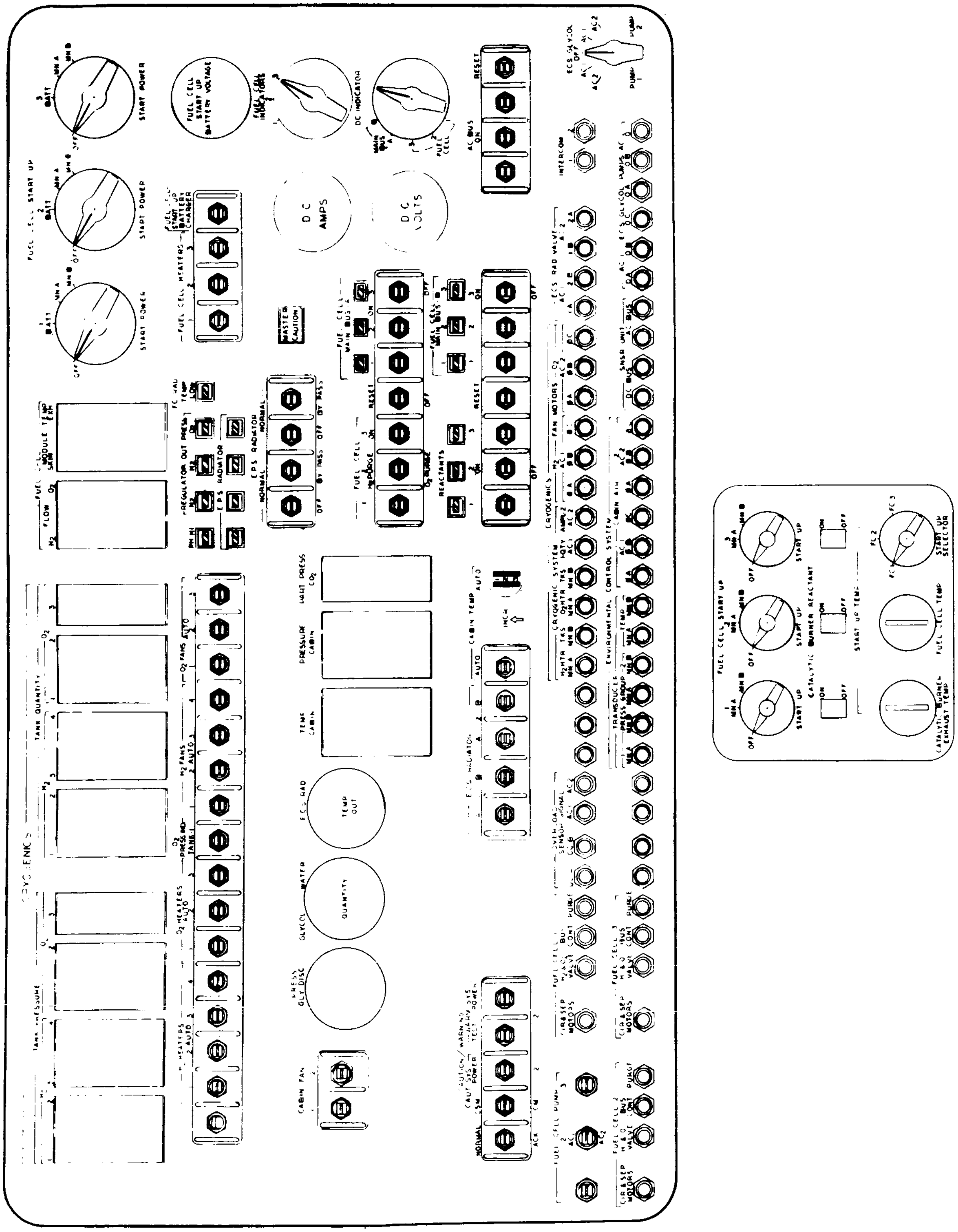

Figure 26. Airlock Control and Display Panel—Configurations D and D'

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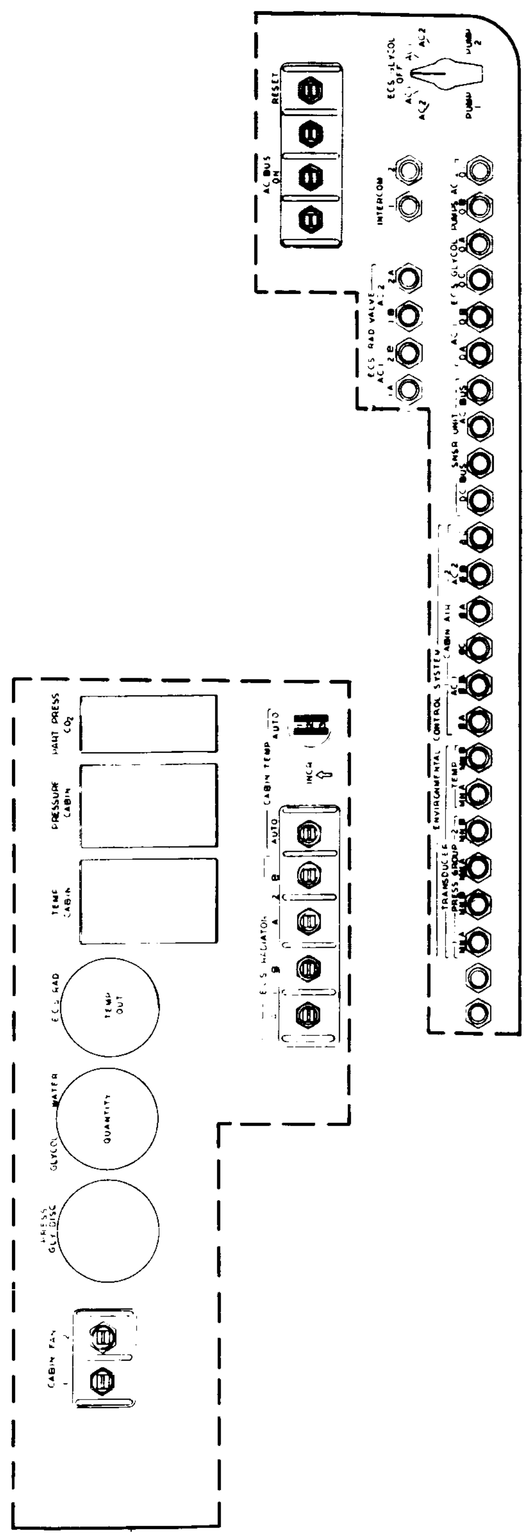

Figure 27. Airlock Control and Display Panel—Configurations 1 and C

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UMBILICALS

As a result of the subsystems analysis, the CM/external device interfaces were defined. These are summarized in Figure 28. All configurations require interfaces with the external device

The SCS interface consists of the extension of one of the CM rotational controller cables so that it can be carried into the external device. A crewman in the external device can then directly control the vehicle attitude.

The power system interface consists of an ac and dc umbilical to connect the CM ac and dc busses with similar busses in the external device. In addition, monitoring and warning for the power system interface will be placed on the righthand control panel.

The ECS interface consists of the installation of retractable duct and blower to provide atmosphere circulation between the CM and the external device.

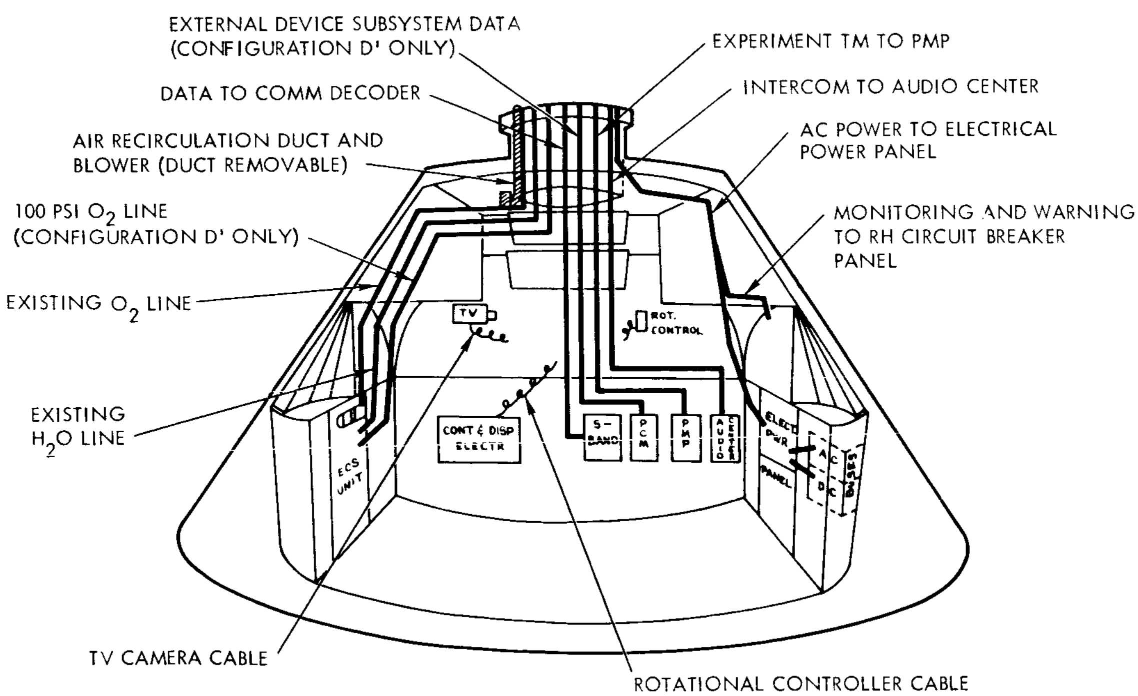

Figure 28. External Device/CM Interfaces

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The communications/data system interfaces involve the transmission of experimental data to the premodulation processor, interconnection of the CM and external device audio centers, and the transmission of up-data commands from the CM S-band equipment to the command decoder in the external device. In addition, provisions are made to extend the TV cable so that it can be carried into the external device.

Configurations D and D' require the following additional items: 100 psi O_2 line to supply oxygen from the external device to the CM ECS; use of the existing H_2O line, and the addition of wiring to the CM PCM telemetry unit to carry subsystem status data.

Configuration C requires additionally only the extension of the existing O_2 line for repressurizing the external device.

CONCLUSIONS

Tables 25 and 26 summarize the changes required for each subsystem for each configuration. The first table summarizes changes for subsystems in the command and service module. The second table summarizes the subsystems for the external device.

CONFIGURATION 1

The subsystems in the CSM are Block II Systems except for communications, environmental control system, and the power system. The communication and data system requires modification to the premodulation processor, the audio center, and the S-band transceiver to accommodate wires for transmission and reception of data to and from the external device. In addition, the high gain antenna would be carried only in synchronous orbit flights and the rendezvous transponder would be carried only in rendezvous flights. The environmental control system requires the addition of a retractable duct and a blower.

The external device requires a power distribution system that would include ac and dc busses and, in addition, batteries would be added for power make-up and to handle peak loads. The ECS in the external device requires a thermal control loop, a contaminant control loop, and a repressurization and depressurization system. The power system in the command module must accommodate an ac umbilical from the ac bus. The communication system in the external device requires an audio center and a data management system to format and condition the experimental data.

CONFIGURATION D'

This configuration contains subsystems in the CSM identical to those of Configuration 1 except for the communication and data system, the earth landing system, and the environmental control system. The communication and data system requires, in addition to the modifications for Configuration 1, modification to the PCM telemetry unit so that it can accept external device subsystem data. The earth landing system requires the addition of volatile material to the parachute compartment and modifications to the insulation and external coating of the parachute compartment. The environmental control system must have the same modifications as in Configuration 1 and, in addition, the compressor, cabin fan, and other items must be made redundant. In addition, a 100 psi 0_2 line that brings oxygen from the external device is interfaced with the command module system.

Table 25. CSM Subsystem Change Summary

Subsystem	Configuration			
	1	D'	D	C
Comm/data	Block II with wiring interface, delete high-gain and rendezvous transponder	Same as 1, plus interface wiring for subsystems data	Same as D'	Same as D
ELS	Block II	Add volatile material	Same as D'	Same as D
ECS	Add blower and duct	Same as 1 plus modified Block II unit with spare compressor and cabin fans plus 100-psi O_2 line	Same as D' plus modified compressor and cabin fans	Same as D less 100-psi O_2
G&N	Block II	Same as 1	Modify IMU, AGC, and ECDU's	Same as D
Power	Block II plus wiring interface	Same as 1	Same as 1	Four 1000-hour cells plus wiring interface
Cryogenic storage	Block II	Same as 1	Same as 1	Four new cryogenic tanks
Propulsion	Block II	Same as 1	Same as 1	Tank size varies per mission requirements
RCS (SM)	Block II	Same as 1	Use LEM tanks (2 sets/quad)	Same as D
SCS	Block II	Same as 1	Modify electronics, add horizon sensors, add redundant units	Same as D

[redacted]

Table 26. External Device Subsystem Summary

Subsystem	Configuration			
	1	D'	D	C
Comm/data	Add audio CTR and data management system	Same as 1, plus signal conditioner for subsystems data	Same as D'	Same as 1
ELS	—	—	—	—
ECS	Thermal control loop and repression system	Same as 1	Thermal control loop	Same as D
G&N	—	—	—	—
Power	Battery for make-up and peaks, plus power distribution system	Power distribution system plus battery for peaks plus three 400-hour fuel cells plus cooling loop	Power distribution system plus battery for peaks plus three 1000-hour cells plus cooling loop	Power distribution system plus battery for peaks
Cryogenic storage	None	7 Block II tanks	4 new cryogenic tanks	None
Propulsion	—	—	—	—
RCS	—	—	—	—
SCS	—	—	—	—

The subsystems on the external device are the same as in the Configuration 1 except for the cryogenics system. The communication system on the external device requires a signal conditioning unit to condition the subsystem data from the external device subsystems. A power distribution system similar to that of Configuration 1 is required, as are batteries to handle peak loads. Three 400-hour fuel cells and a cooling loop including radiators are required. To supply reactant to the power system and oxygen for the crew, seven Block II tanks must be installed in the external device.

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CONFIGURATION D

The changes to the command module subsystems are the same as those for Configuration D' or 1, except for the environmental control system, the guidance and navigation system, the service module RCS, and the SCS. In the enrironmental control system, the compressor bearings and cabin fan bearings are modified to accommodate the longer mission life and some small components are made redundant. The guidance and navigation system requires modification to the inertial measurement unit, the guidance computer, and the coupling display unit to allow some portions of this to be turned off when not in use; the system also requires modifications to accomplish the mission requirements such as stringent attitude hold or local vertical hold for long periods. The reaction control system in the service module uses LEM tankage (two sets per quad) to accomplish the experimental requirements. The SCS requires redundancies and the addition of horizon sensors and modification to some electronic units so that they can accept the horizon sensor outputs. The addition of the horizon sensors provides a local vertical hold capability.

The subsystems in the external device are the same as for Configuration D' except for ECS, power, and cryogenic storage systems. The ECS requires only a thermal control loop and no repressurization system, since this is provided by the cryogenic storage system. The power system requires the power distribution system and batteries, as in Configuration D'. However, three 1000-hour fuel cells are carried, plus a cooling loop including radiator. The Apollo X type tanks are carried for the cryogenic storage system; hence, fewer tanks are required.

CONFIGURATION C

The subsystems in the command and service module are the same as those for Configuration D except for the ECS, power, cryogenic systems and the propulsion system. The ECS is the same as in Configuration D except that the 100-psi oxygen line is deleted because no cryogenics are carried in the external device. Otherwise, it incorporates the same modifications as were required for Configuration D. The power system uses four 1000-hour fuel cells and must accommodate the same wiring interface as in Configuration 1. To supply reactant for the fuel cells and oxygen for the crew, Apollo X type tanks are carried in Sector 1 and 4 of the SM. The propulsion system uses smaller tank sizes than Block II and it appears that tanks of 10,000-pound capacity total will suffice for all missions except those for which Block II tanks are required. The subsystems in the external device are the same as in Configuration D except for the deletion of the fuel cells and cooling loop in the power system, deletion of cryogenic tankage, and the deletion of the signal conditioning unit for subsystem data.

DEVELOPMENT PLANNING

This section summarizes the results of the development planning studies presented in Volume 5, which include the results of identifying, programming, and costing the AES program requirements for spacecraft, experiment modules, and subsystems. Functional areas have been analyzed in detail to identify requirements, planning factors, and time-span pre-requisites pertinent to developing a logical, evolutionary program plan that will achieve the goal of Earth-orbital mission launches consistent with NASA AES program objectives in consonance with Launch Planning Schedule AE 65-1.

Functional area analyses performed in this study include engineering design and development; development and qualification testing; fabrication, systems installation, and checkout; pre-launch and launch operations; and ground support equipment, transportation, facilities, and logistics.

APPROACH

The initial development planning ground rules applied during the study were augmented and modified by both oral and written guidance from NASA as the study progressed. The final ground rules and guidelines are as follows:

1. The AES program will not interfere with the Apollo lunar landing program.

2. The Apollo Block II program, as identified in Apollo Master Development Schedule No. 8, Revision 3 (Figure 29) and the Apollo program exercise for a CSM production rate of eight per year after SC 112, will be used as the baseline in determining the delta requirements and costs occasioned by the AES program.

3. Launch dates and booster availabilities for AES missions will be as identified by NASA Schedule AE-65-1, "1966-71 Saturn Launches for Planning Purposes," 11 February 1965 (Figure 30).

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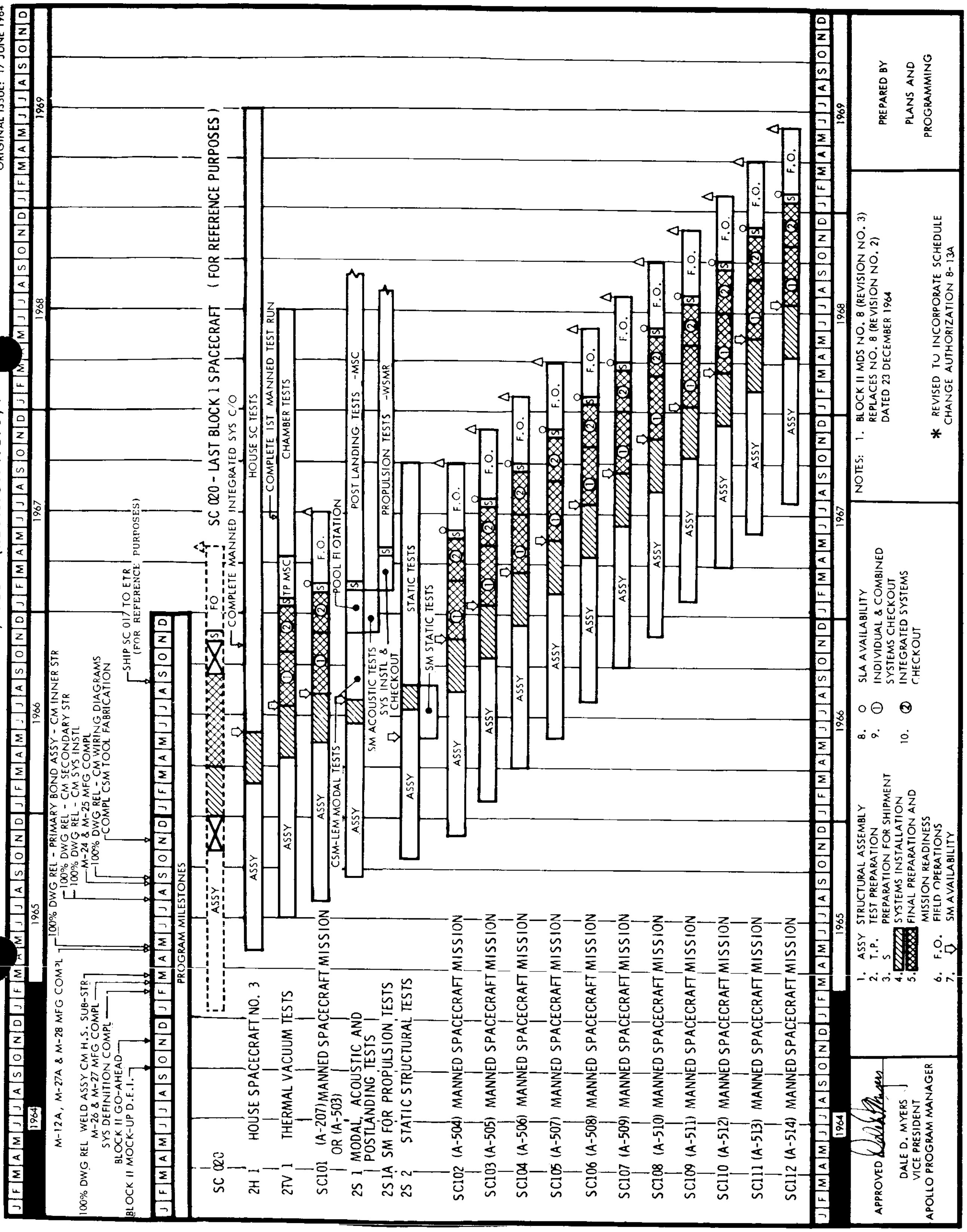

Figure 29. Apollo Block II Master Development Schedule No. 8

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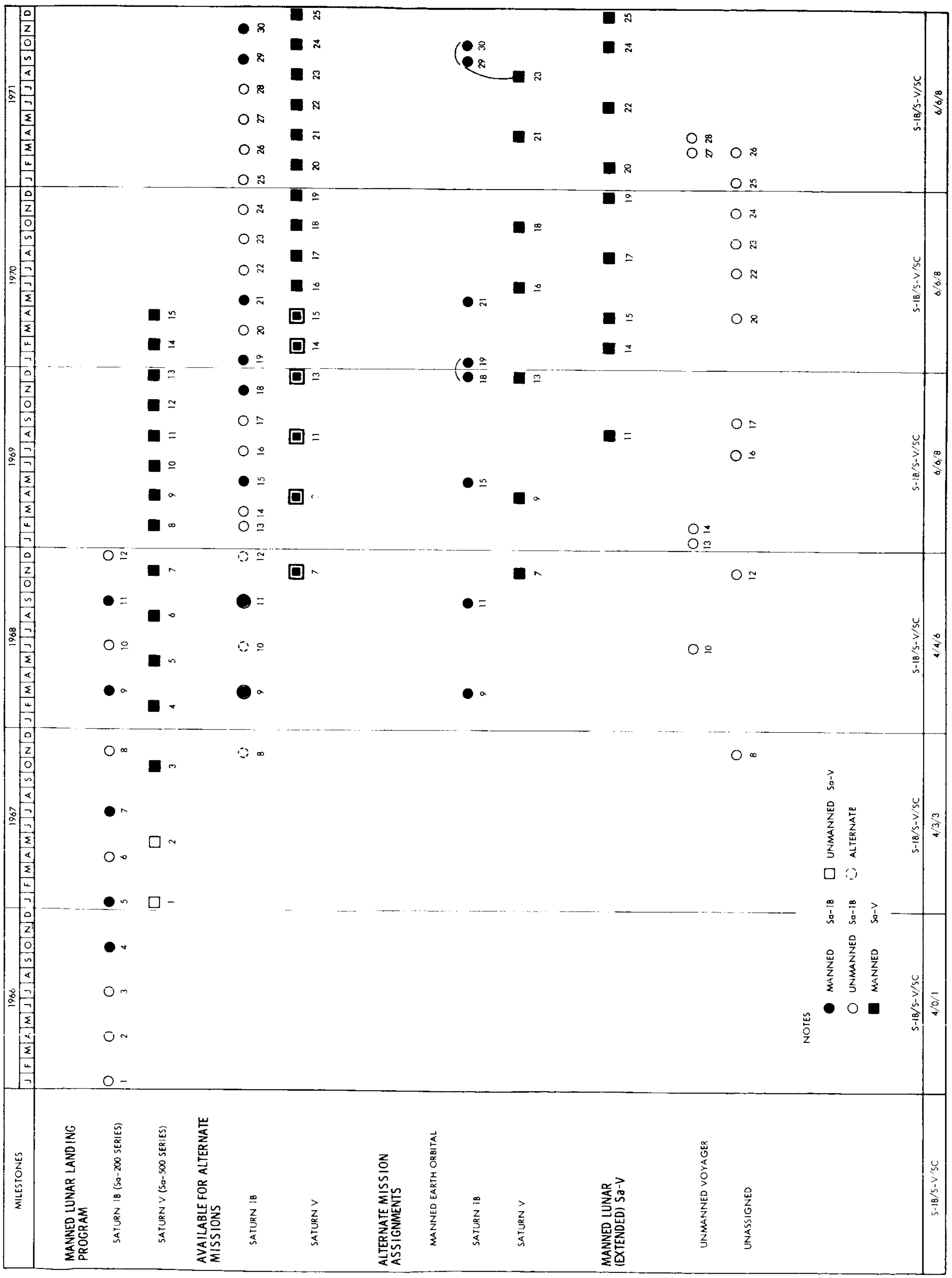

Figure 30. AE 65-1 Booster Schedule (1966 to 1971 Saturn Launches for Planning Purposes)

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4. Four spacecraft configurations (1, C, D, and D') will be studied for accomplishing AES missions. Development planning, however, will exclude the C configuration, since it was accomplished in the previous Extended Apollo Systems Utilization Study.

5. Accomplishment of early AES missions per NASA Schedule AE 65-1 will be accomplished by diverting five spacecraft from the Block II Apollo program after delivery to KSC and modifying them as required for the 14-day and 30-day missions. All AES missions after SC 112 will be accomplished with Block IIA spacecraft — i.e., Block II spacecraft into which structural and subsystem scars have been provided so as to permit modification into AES mission configurations at a late stage in assembly. Block IIA will be a Block II follow-on program, with an in-line block change effective on SC 113.

6. Delta costs over Block II Apollo will be identified for Configurations 1, D and D' and broken out by:

   (a) Phase (design and development, production, and operations)
   (b) Configuration (Block II modification, Block IIA, pallet, and experiments appendage)
   (c) Requirement (life-extension or experiment-peculiar)
   (d) Subsystems (to include structures, G&N subsystem, space spacecraft-LEM adapter, and GSE).

   Facilities costs will be identified separately. Costs will be based on 1965 dollars, fee excluded, using current overhead rates, and with G&A spread over the total program. Nonrecurring costs for an accelerated production rate of 14 spacecraft per year will be established in a separate, rough-order-of-magnitude study.

7. Development planning and costing for the design, development, and qualification of experiments packages will be performed under a separate NASA contract to the International Business Machines Corp. S&ID's development planning for experiments will be confined to installation, integration, and integrated checkout of GFE experiments in the pallet or experiments appendage for 15 AES Earth-orbital flights.

8. S&ID development planning will exclude support requirements for flight operations (e.g., MSCC modifications, mission control and recovery, etc). Normal contractor support, however (e.g., in pre-launch checkout), will be included.

The above NASA directives, guidelines, and ground rules provided the point of departure for the AES development planning study.

Because of the abbreviated time allowed for completion of the AES study, the usual serially phased sequencing that is normally employed had to be performed in parallel with the technical analyses. Planning effort was initiated in all functional areas before the experiments profiles had been established, the subsystem requirements to support them identified, or the vehicle configurations defined. Accordingly, a number of additional NAA-established assumptions were required, both at the outset and throughout the study, whenever it was found that interface or input information for further planning was yet undeveloped. The more influential of these assumptions and ground rules were as follows:

1. Go-ahead for Phase D will be 1 May 1966, preceded by a nine-month Phase B and C effort, during which mock-ups will be designed and fabricated, and a design engineering inspection (DEI) accomplished. Development and qualification testing will also begin in Phase C.

2. Maximum use will be made of existing Apollo hardware and technology.

3. A standard basic structure will be used for both the rack and pallet. (The pallet design was performed under a separate Apollo Block II Study.)

4. No additional spacecraft will be required for structural, thermal vacuum, or house spacecraft testing; Block II test spacecraft will be refurbished and/or modified for this purpose.

5. Modifications on Block II spacecreft for the first five AES missions will be performed by S&ID personnel at KSC facilities.

6. Block II service modules will have been designed, fabricated, and qualified in accordance with CCA 317 for the accommodation of a pallet in SM Section I.

7. All AES missions will be performed within the Apollo Block II design and performance envelope (vibration, shock, etc.)

8. Development planning will be based on producing 23 Block II A spacecraft (to include AES lunar as well as Earth-orbital missions), 37 racks (four test articles, 28 flight articles, and 5 spares without subsystems), and 32 experiments pallets (4 test articles and 28 flight articles).

9. All AES hardware will be air transportable by B-377PG aircraft.

These additional assumptions and ground rules made it possible for the various functional elements to initiate development planning on a concurrent basis with the technical requirements studies.

Continuous coordination and interchange of information were effected as results from the engineering analyses became available. Maximum use was made of data available from the Apollo program and from applicable results of previous Extended Apollo Systems Utilization Studies. As the functional area requirements in materials, equipment, manpower, and facilities were defined, they were integrated into preliminary total program requirements and schedules. Incremental inputs of design information, interface requirements, and schedule conflicts required continual refinement of preliminary planning on both a functional and integrated basis, but major schedule perturbations diminished in each successive iteration until it became possible to integrate the various functional requirements and activities into a total program that would meet AES objectives.

Alternate analyses were performed and a schedule was prepared, to show a total program based on the same production rate (eight per year) with an earlier conversion to the Block IIA CSM configuration (on SC 108 rather than on SC 113).

At NASA request, an additional, rough-order-of-magnitude study was performed to ascertain program feasibility and nonrecurring costs of an accelerated CSM-SLA schedule of 14 deliveries per year. Schedule and costing for the accelerated schedule are presented in Volume 5.

ENGINEERING DESIGN AND DEVELOPMENT

CONFIGURATION ANALYSIS REQUIREMENTS

The Engineering investigations performed during this study were concerned with developing design characteristics of spacecraft configurations to support the 15 AES missions and experiment groupings defined by NASA at the beginning of the study. Configuration 1 vehicles will be used on the first, third, fourth, and fifth launches, which are 14-day missions; Configuration D' on the second launch, which is a 30-day mission; and Configuration C and D were both studied for use on the sixth through fifteenth missions. For development planning purposes, however, only Configurations 1, D, and D' were considered, in that development planning for Configuration C was essentially that provided for the previous Extended Apollo Systems Utilization Study.

Analysis indicated that development planning factors could be more clearly defined by segmenting the development planning effort into four separate packages in consonance with the four major elements studied for the AES Earth-orbital program — Block II (modified), Block IIA, Pallet, and Rack.

Engineering design and development requirements were established based on the designs identified for each of these packages and then applied to develop the engineering plans and schedules shown in Volume 5.

DESIGN AND DEVELOPMENT PLANNING FACTORS

An analysis of the technical requirements for the AES program was performed and schedules prepared to show the design and development milestones required to accomplish the program. These schedules and milestones were prepared to reflect systems engineering requirements and program phasing terminology of NASA policy document "Phased Project Planning" (draft), 11 February 1965, and are consistent with concepts outlined in the NASA Apollo Configuration Management Document, NPC-500-1.

Information presented on the schedules was derived from the planning of a technically sound and logically sequenced design and development program to meet program objectives within available time and resources with a high confidence level. Schedules were developed on an integrated, concurrent basis with other development planning functions, and are coordinated and interfaced with other related functional schedules presented later in this section.

In the preparation of schedules, it was assumed that the definition phase (Phase B and C) would provide the necessary systems engineering documentation, preliminary design/preliminary detail design (CEI) specifications and full-scale mockups. Early availability of documents and mockups is essential for an efficient transition to be made from preliminary design to detailed design, fabrication, test, and operations.

Engineering Phasing Schedule

The schedule in Figure 2, Volume 5, shows (1) major milestones, (2) systems engineering, and (3) engineering design and development. Major milestones reflect the phasing of major program segments and identify target dates for major program events. The assumed nine-month combined Phase B and Phase C effort leads directly into the Phase D effort, which encompasses a two-year detail design and development program for the Block II modifications and Block IIA Spacecraft following the Block II program.

Schedule compression is necessary due to the April 1968 target date for launching the first 14-day AES mission, based on the assumed 1 May 1966 date for Phase D go-ahead. The most critical aspect of the program is the qualification of new and existing structures, materials, and subsystems to perform reliably for missions beyond 14 days. Accordingly, development/qualification testing activities are initiated in the Phase C program, before Phase D go-ahead.

Configuration management milestones have been included with major milestones and indicate the target dates for establishing the program requirements baseline, the design requirements baseline, and the product baseline. Use of the baseline management concept provides an orderly transition from one portion to the next.

The systems engineering milestones reflect heavy emphasis on preparation of definition-type documentation during the Phase B and C effort. Subsequently, during Phase D, these documents will be refined, updated, and expanded to include results of detailed engineering investigations and designs. In this manner, the total AES program requirements are in focus at any point in time, with the systems engineering documentation serving as the baseline of accountability for every contract end item and every element of the program.

Reviews are scheduled earlier than than others to allow sufficient time for meeting the constraining pallet, rack, and modified Block II 100-percent drawing release target dates. Mockup drawings will be released coincident with configuration selection, allowing a limited but sufficient time for mockup fabrication before the mockup design engineering inspection.

Detail designs and Part I of contract end item (CEI) specifications will be required in Phase C for Block II CSM modifications, pallet, and rack to provide a firm base for initiating procurement. Since more time is available for Block IIA, only preliminary design drawings and preliminary contract end item specifications (Part I) will be required in Phase C.

SUBSYSTEM DEVELOPMENT AND DELIVERY

Subsystem development and delivery requirements for the AES program are shown in Figure 3, Volume 5. The gross development milestones for the subsystems of each of the four major hardware elements underline the importance of timely availability of these subsystems for development and qualification testing. It is anticipated that more detailed analysis in Phases B and C will further refine and identify unique and specific requirements that may modify these milestones. As a result of the analysis to date, however, it is apparent that development and qualification of extended operating and new hardware for the mission durations and environments required by the AES missions is the pacing activity of the entire program.

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TEST REQUIREMENTS AND TEST PLANS

Test requirements and plans were developed in an analytical, evolutionary process that began with the performance requirements imposed on materials, structures, and subsystems by AES mission profiles. In view of the study objective to make maximum use of existing hardware, much of the qualification testing will be on present Apollo materials, structures, and subsystems to establish their ability to operate for the longer AES mission durations. New hardware items, like rack, pallet, and the SM Sector I jettisonable cover, will require the entire gamut of development and qualification testing. Four racks, pallets, and new SM Sector I covers have been scheduled for static, dynamic, thermal-vacuum, and house spacecraft testing. Block II test CSM's will be modified as required to support AES testing.

To support Configurations 1, D' and D (14-day, 30-day, and 45-day missions, respectively) the development/qualification test requirements for the rack, pallet, modified Apollo Block II, and Apollo Block IIA were investigated. Tradeoff studies were made to establish criteria for the level(s) at which testing should be conducted - i.e., component, subsystem, or integrated system — to provide maximum assurance of meeting mission objectives consistent with schedule constraints. The level and type of development/qualification test requirements established for each major hardware item are summarized in Table 2 in Volume 5, A more comprehensive presentation of development/qualification test requirements and objectives is also shown in Volume 5.

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MANUFACTURING PLANS

Detailed manufacturing analyses and tradeoff studies were performed in an effort to provide the best approach for implementing the AES program on a noninterference basis with Apollo Block II manufacturing. The results of these analyses and tradeoffs, and a plan for implementing AES manufacturing requirements, are fully described in Volume 5 of the AES study report, and summarized in these pages.

The manufacturing plan is divided into four parts, conforming to the four basic hardware configurations considered in the AES study: Block II CSM (modified); Block IIA CSM; experiment pallet; and experiment/subsystems rack. Fabrication and assembly sequences for each of these four major items have been determined, delta tooling and special measuring devices (SMD) requirements have been identified, and schedules have been prepared indicating the phasing of the new manufacturing requirements generated by the AES program.

BLOCK II CSM MODIFIED

Block II spacecraft to be used on AES missions (spacecrafts 103, 105, 107, 109, and 110) will have been delivered to KSC in the Block II configuration. To convert these spacecraft to AES mission configurations requires the installation of modification kits in the command module, the addition of an experiments pallet in Sector I of the service module, installation of a jettisonable SM Sector I cover, and installation of an experiments/subsystems rack in the spacecraft LEM adapter (SLA).

The Block II CM modification kit will include wire harnesses and cables, junction boxes, air recirculating ducts and fan, an O_2 line (for the 30-day mission only), an additional ECS compressor, and other pertinent plumbing occasioned by the rack/CM interface. Modification of the SM at KSC will consist only of removing the Block II cover panel, installing the pallet, and installing the jettisonable cover panel.

BLOCK IIA

An in-line change from Block II to Block IIA is primarily concerned with the service module structure. Additional fabrication and tooling requirements are generated by this change.

Basically, the Block IIA configuration varies little from Block II, with approximately 51 pounds of added scar weight and other changes that permit installation of various types of subsystems thereby,providing the flexibility for performing either Earth or lunar AES missions.

Command module modifications consist essentially of adding two sensor windows and making changes to the inside secondary structure and subsystems. Existing tooling will be modified for most of the requirements, but some new tooling must be fabricated.

Modifications will also be required on SMD and GSE used with both CM and SM; however, there is no significant change in checkout philosophy or use of facilities for the Block IIA CSM.

EXPERIMENTS PALLET

The pallet is a modular, wedge-shaped structure that will completely occupy SM Sector I when installed. It employs riveted box-beam longerons, riveted skin-stringer panels, bonded bulkheads, bonded coldplate-type equipment shelves, and tubular coolant manifolds running through the longerons. The pallet is a new element and will require completely new design, tooling, SMD, and GSE. It will require fabrication and assembly on a production line separate from the present Apollo service module and command module assembly lines. Although its basic skin-stringer structure and water/gylycol cooling require the latest manufacturing techniques, they are similar to those that have been successfully performed in the current Apollo manufacturing program.

EXPERIMENTS/SUBSYSTEMS RACK

The experiments/subsystems rack is also a new design. It consists of a cylindrical airlock compartment centered in a structure in the shape of a truncated cone tapered to the internal mold lines of the SLA. Rack construction includes honeycomb sandwich-construction upper and lower bonded bulkheads; flat plate radial beams; removable skin panels of skin-stringer construction; experiments shelves of bonded honeycomb sandwich construction, some containing coolant radiators; and base structure with attach members to tie into the LEM attach points in the SLA.

All of the manufacturing techniques required in rack fabrication are considered standard, having been used previously in S&ID manufacturing. Tape-controlled machining and advanced explosive forming techniques will be required in fabrication of the airlock. The latest techniques in intricate welding will be required, but will not extend beyond present experience in performing difficult welding requirements on Apollo and, in particular, Saturn S-II. Being completely new and a large-size hardware item the rack must be assembled on a new and independent assembly line.

SCHEDULES

First article manufacturing time spans and production schedules were developed for each major hardware item, and are presented in Volume 5. They represent the result of detailed analysis of manufacturing techniques and flow times, manpower requirements, and the lead times required for engineering releases, initiation of procurement, and fabrication or modification of tooling. They are based largely on Apollo experience in the manufacture of similar articles. A master schedule for AES program manufacturing is presented in Figure 11 of Volume 5.

PRELAUNCH CHECKOUT OPERATIONS

Delta prelaunch checkout operations generated by the AES program have been prepared with the Apollo Block II program operations as baseline. Operations include Downey checkout, checkout of the spacecraft at the KSC facilities, and pad operations.

Mission Configurations 1, D', and D require modifications to the spacecraft, but will have little effect on spacecraft checkout at either Downey or KSC. Checkout of rack and pallet systems and their integration with spacecraft systems, however, will add extra functions to the spacecraft checkout operations both at Downey and KSC.

For Downey operations, the additional functions required are: rack and pallet pressure check, noncritical experiment installation, weight and balance calibration, installation of the pallet in the SM, qualification verification vibration test, design engineering inspection, configuration updating, and cleaning. The functions to be performed concurrently with CSM checkout functions are individual and combined systems checkout, installation of critical or classified experiments, integrated system checkout, and removal of critical or classified experiments. Despite these additional functions, the time in checkout operations at Downey will remain essentially unchanged from the Apollo Block II program. Details of the operation flow sequence and times are shown in Volume 5, Development Planning. No additional acceptance checkout equipment (ACE) or floor space in Building 290 at Downey will be required to accommodate these additional checkout requirements.

KSC operations will include modification of Block II spacecraft for Configuration 1 and D'. Aside from the modification time, the times for AES checkout operations at KSC, including the additional functions of checkout and integration of rack and pallet systems, will remain essentially the same as for the Apollo Block II program. For the rack, the additional functions are: receiving and inspection, fit-check with the CM, fit-check with the SLA, cryogenic system checkout, fit-check of critical experiments, installation of noncritical experiments, weight and balance calibration, ECS test, and system checkout in the altitude chamber. For the pallet, the additional functions are: receiving and inspection, fit-check with the SM, fit-check or installation of experiments, and installation of the pallet in the SM. The functions to be performed concurrently with CSM checkout functions are electrical mating of CSM, SLA, and rack, integrated systems checkout, and polarity check. Critical experiments will be installed in the rack prior to installation of the rack in the SLA, and in the pallet prior to CSM mating with the SLA. Alternate provisions have been made to defer the installation of critical experiments, if required, until the CSM mates with the Saturn IB on Pad 34 or 37, or with the Saturn V in the VAB.

The present facilities at KSC provided for the Apollo Block II program will be sufficient to support the AES program, with possible additional requirements in experiment preparation and storage areas. Further details on facilities requirements are presented in the Facilities section of this volume and in volume 5.

GROUND SUPPORT EQUIPMENT AND TRANSPORTATION

The ground support equipment required for the various configurations described in this report is drawn largely from the inventory of existing Apollo GSE. Certain modifications are required to extend the capability of existing equipment, and some new equipment is required to support AES-peculiar configurations. The similarity of modules and subsystems in the AES and Apollo configurations minimizes the amount of new and modified equipment.

In the following paragraphs, new or modified GSE requirements for each of the four major hardware configurations (Block II modified, Block IIA, pallet, and rack) are identified. The minor impact of the AES program on the present Apollo transportation plan is presented in the closing paragraphs of this section. A more detailed discussion of GSE and transportation required to support the AES program is presented in Volume 5.

BLOCK II MODIFIED

There are no requirements for GSE peculiar to the Block II modification. Existing or planned GSE for Block II will support the modification kits for the CSM and the modified CSM.

BLOCK IIA

Support equipment for Block IIA consists of existing Block II GSE, except for the following modifications and additions to auxiliary and handling equipment:

Cap and Plug Set (A14-026) — Will require new or differently sized mechanical, hydraulic, and electrical opening covers.

Fuel Cell Heater Power Supply (A14-052) — Heater panels added to accommodate the new fuel cells.

Fuel Cell Radiator Substitute Unit (A14-059) — Additional radiators required to accommodate the new fuel cells.

Service Module Equipment Dolly (H14-121) — Requires replacement of the tie-down straps.

Spacecraft Integrated Systems Workstand (H14-124) — Alterations for new access requirements.

Umbilical Disconnect — New umbilical disconnect required between the rack and GSE.

Equipment Installation Fixture — Required for installation and removal of the different-sized LO_2 and LH_2 tanks (also for fuel cells in the rack).

Cryogenic Tank Protective Covers — For the different-sized LO_2 and LH_2 tanks.

PALLET

The only new items of equipment required to support the pallet are handling-type equipment for the removal and installation of the pallet from and into the SM, and from and into its shipping container. Certain items of existing Apollo checkout equipment can be modified to satisfy the pallet subsystem requirements. New and modified GSE requirements include the following:

Pallet Installation Fixture — For installing the pallet in the SM.

Pallet Storage Base — For pallets with subsystem components and experimental equipment installed.

Pallet Sling Assembly — For pickup from shipping container.

Antenna Checkout Group (C14-032) — Modification required for checkout of the omnidirectional antenna.

Environmental Control System Major Subassembly Bench Maintenance Test Stand (C14-121) — Modification required to test augmented components of the Environmental Control Unit.

RACK

New auxiliary and handling equipment is required because the large size of the rack makes modification of existing equipment infeasible. Existing Apollo checkout equipment can be modified or augmented to serve the new requirements, with the exception of one cable set. New and modified GSE requirements include the following:

Upper and Lower Handling Rings — For lifting and manipulation of the rack, and to protect the rack in stacked storage.

Cleaning Positioner — For rotating the rack around two of its axes, for proper cleaning after fabrication.

Rack Support Base — For convenient access to the lower hatch when equipment is being installed or checked out.

Rack Access Ladder — For entry to the lower hatch when the rack is mounted on its support base.

Rack Sling — For lifting the rack.

Rack Rollover Adapter — For installation in the cleaning positioner or transport dolly.

Rack Transport Fixture — For supporting the rack in the B377PG aircraft; also to support the rack during high-pressure leak tests in Building 260 at Downey.

Rack Transport Cover — For environmental protection during transport and storage.

Cap and Plug Set — For closure against dust, moisture, insects, etc.

Rack Substitute Unit — For simulating the rack/CSM interface when it is not feasible to employ the rack.

Work Stand — For working at the various levels of the rack when it is on the support base.

ACE - SC Carry-On Cable Set — Additional wiring required.

ACE - SC Carry-On Junction Box (C14-202) — Modification required.

Umbilical Cable Set — For connecting the rack and CM subsystems during integrated test operations.

TRANSPORTATION

Preliminary analysis of AES transportation factors indicates that little change is required to the existing Apollo transportation plan. Command modules and service modules will be air shipped by B-377PG aircraft, as at present. Air shipment of the rack, pallet, and their supporting equipment from the S&ID Downey manufacturing facility to Cape Kennedy also is considered the best method of transport.

The rack is the only AES hardware item that could possibly pose transportation problem, because of its size. Minor modifications to its preliminary design, however, will permit it to fit into the B-377PG with tight clearance but with no sacrifice in rack payload volume. AES pallets and supporting equipment may accompany the rack aboard the same aircraft.

In the event airlift is not available, or if changes to the present rack configuration preclude air transport, water transport may be designated as an alternate mode.

FACILITIES

The AES facilities study was performed to determine the additions and/ or modifications necessary to implement the AES program. It was assumed that all facility modifications necessary to meet the Apollo Block II will have been implemented by the inception of the AES program. For purposes of this study, utilization of facilities in support of the AES program are identified as follows:

	Pallet	Rack	Block II	Block IIA
Development	Downey	Downey	Downey	Downey
Fabrication and Assembly (Structures)	Tulsa	Tulsa	SM-Tulsa CM-Downey SLA-Tulsa	SM-Tulsa CM-Downey SLA-Tulsa
Systems Installation and Checkout	Downey	Downey	Downey	Downey
Modification	---	---	KSC	---
Noncritical Experiment Installation	Downey KSC	Downey KSC	---	---
Critical Experiment Installation	KSC	KSC	---	---

BLOCK II MODIFICATION

The additional facility requirements generated by the Block II modification program consist primarily of the following:

1. Additional special test equipment to be procured and installed in the S&ID Engineering Development Laboratory in Downey. This equipment is required to augment existing equipment for breadboard testing, calibration, measurement, and evaluation of Block II materials and subsystems for their ability to complete a 30-day mission (Flight 211).

2. Additional floor area in or adjacent to the Operations and Checkout Building at KSC to support modification activities and experiment preparation without interference to Apollo lunar landing program activities.

BLOCK IIA

Facility changes necessary to support this phase of the AES program consist mainly of minor rearrangements to accommodate tool modifications and provisions for storage of new apply jigs. The additional special test equipment identified for Block II modification will continue to be used in testing Block IIA subsystems for their ability to sustain 45-day missions.

PALLET

Structural fabrication and assembly of the pallet will be performed at the Tulsa facility. An additional 10,000 square feet of factory area must be provided, prepared, and equipped.

Installation of subsystems and experiments and checkout of the completed pallet will be performed in Building 290 at S&ID Downey. Additional handling devices are required to support the pallet during installation and checkout.

RACK

Structural fabrication and assembly of the rack will be performed at the Tulsa facility. An additional 30,000 square feet of factory area must be made available, prepared, and equipped. Other requirements include material handling equipment, machine tools, and sheet-metal fabrication tools.

Installation of equipment shelves, subsystems, and experiments, and checkout of the rack with its respective CSM, will be performed in Building 290 at S&ID Downey. A rearrangement is necessary to accommodate the rack systems installation stand, the rack checkout stand, and the qualification verification vibration test stand.

Pressure testing of the rack's cryogenic tanks and plumbing system will be performed in Building 260 at S&ID Downey. Use of a device similar to the transport dolly (GSE) will permit testing of the rack in the existing SM pressure cell. Systems integration and checkout will be performed in Building 290, S&ID Downey. In addition to the rearrangement necessary to accommodate the rack checkout and installation stands, provisions must be made for the installation of a rack cleaning positioner in the south end of the high-bay area and the installation of a cover over the pit to be used for the weight and balance station.

No increase in the number of CSM checkout stations and ACE systems will be required by the introduction of the pallet and rack into the Building 290 operations.

ALTERNATE SCHEDULE NO. 2 FACILITY REQUIREMENTS

The delivery rate (14 spacecraft per year) required on Alternate Schedule No. 2 exceeds available capacity in most areas of spacecraft assembly and checkout. Additional tooling requirements are anticipated in most fabrication and assembly areas. Accommodation of these tools will necessitate layout changes and additional support equipment.

Prime impact will be in the following areas:

1. Bonding (Building 287 Downey) - Additional area and autoclave capacity.

2. Pressure Test Cell (Building 1 Downey) - Expansion to meet schedule for pressure testing of subsystems and command modules.

3. Systems Integration and Checkout (Building 290 Downey) - Expansion of building to house two additional ACE systems, one additional systems installation station, two additional individual and combined checkout stations, and two additional integrated checkout stations. Expansion must include service equipment rooms for installation of GSE.

LOGISTICS

The logistics portion of the AES study was concerned with identifying the logistic support requirements for the CSM-pallet-rack configurations and their impact on the existing Apollo logistics program, to include field modifications, maintenance, spares, training, technical assistance, and technical documentation.

BLOCK II MODIFICATION

Five Block II CSM's will require modification in order for them to perform the prescribed AES missions. These spacecraft (103, 105, 107, 109, and 110) will require rework at KSC on both the command module and the service module. The major changes in the CM are generated by the requirement to be able to mate with an external appendage (e.g., rack). They concern the environmental control system, electrical power system, communication and data, and crew systems.

On flights requiring installation of an experiments pallet or mapping and survey package, the service module also will require replacement of its Sector I cover panel with a jettisonable panel. The SM modification effort at KSC will be reduced by the application of CCA 317, which provides for the changes to permit the Block II SM to accommodate a mapping and survey kit or experiments pallet in Sector I.

NAA will be responsible for the modification program at KSC. A modification team of supervisory, inspection, and maintenance personnel will be assigned to the modification program for the 17-month period during which the five spacecraft are to be modified. The time scheduled for the CSM to be readied for Configuration 1 AES missions is three months, whereas five months have been allocated for the more extensive D' configuration modification.

The modification program will utilize existing KSC facilities and GSE. Assuming a go-ahead date of May 1966, the modification program will run for approximately 31 months, until February 1969. Specific design and support requirements for the modification program will be determined during the first 14 months. The following 17 months' activity will include the monitoring and support of the modification kits, requirements, and team by Downey personnel, and the actual modification program at KSC.

[redacted]

BLOCK IIA

Minimal impact on logistic support is anticipated from the change to Block IIA. Some Block II GSE will require modification to support Block IIA. The GSE rework will be performed, utilizing GSE modification kits, at KSC by the NAA modification team.

PALLET AND RACK

The usual logistics planning for support of new hardware will be required. In addition, new or modified items of GSE to support the pallet and rack are required. Necessary rework of modifiable GSE will be performed by the logistics modification team at KSC.

EXPERIMENTS

Although the experiments contractor is responsible for checkout and necessary support of experiments, NAA will be responsible for maintaining the environment required by experiments after they have been installed in the rack or pallet, with conditioning equipment to be provided by NAA.

[redacted]

DEVELOPMENT PROGRAM

Previous paragraphs of this section have presented the development planning factors, requirements, and plans for the major functional areas of the AES program -- engineering design and development, test requirements and plans, manufacturing, prelaunch operations, GSE, transportation, facilities, and logistics. These plans were combined and integrated into two alternate master schedules for the AES program, either of which is capable of achieving AES objectives within available resources and time, and with minimum impact on the current Apollo lunar landing program. The first or basic master schedule (Figure 31) is based on an eight-per-year production rate, with a change point from Block II to Block IIA on SC 113. An alternate schedule (Figure 35 in Volume 5) is also based on an eight-per-year rate, but assumes an earlier change point on SC108.

Another alternate schedule (Figure 36 in Volume 5) is based on an accelerated, 14-per-year production rate, which is considered the maximum rate feasible without major impact on facilities, tooling, GSE, etc. The impact on facilities occasioned by the accelerated schedule is identified in the facilities section of this volume.

The first step in the genesis of these master schedules was the preparation of a gross preliminary schedule, combining spacecraft and booster availability into SC/booster assignments that met the AES study objective of launching AES missions at the earliest possible time, consistent with other program objectives, and minimizing standby time for either boosters or spacecraft. The assumptions, factors, and rationale used in developing this preliminary schedule are outlined in Volume 5.

This gross preliminary schedule was released to all functional groups to provide them with a baseline and point of departure for early problem identification and resolution. Development planning factors and requirements were then identified, analyzed, and integrated in each functional area and were laid out in preliminary schedules. These preliminary functional development plans were then integrated into revised total program schedules. This process was repeated as additional information became available until after several iterations the functional area requirements became more firm, major schedule perturbations were eliminated, and it became possible to integrate the scheduled functional activities into a total program major milestone schedule that would meet all AES program objectives (Figure 32).

BASIC SCHEDULE

The basic schedule (Figure 31) assumes a production rate of eight spacecraft per year. The assumed go-ahead date of 1 May 1966 would mark the beginning of major development activity. It would be preceded by a nine-month preliminary/final design phase.

The most critical aspect of the AES program in the basic schedule (as well as the alternate schedules) is the development and qualification testing of new and existing materials, structures, and subsystems for their ability to perform for extended durations in a space environment or 100 percent oxygen environment. To provide a minimally acceptable period for this critical activity, qualification testing of pallet, rack, and Block II modification kit is scheduled to begin during the final design phase.

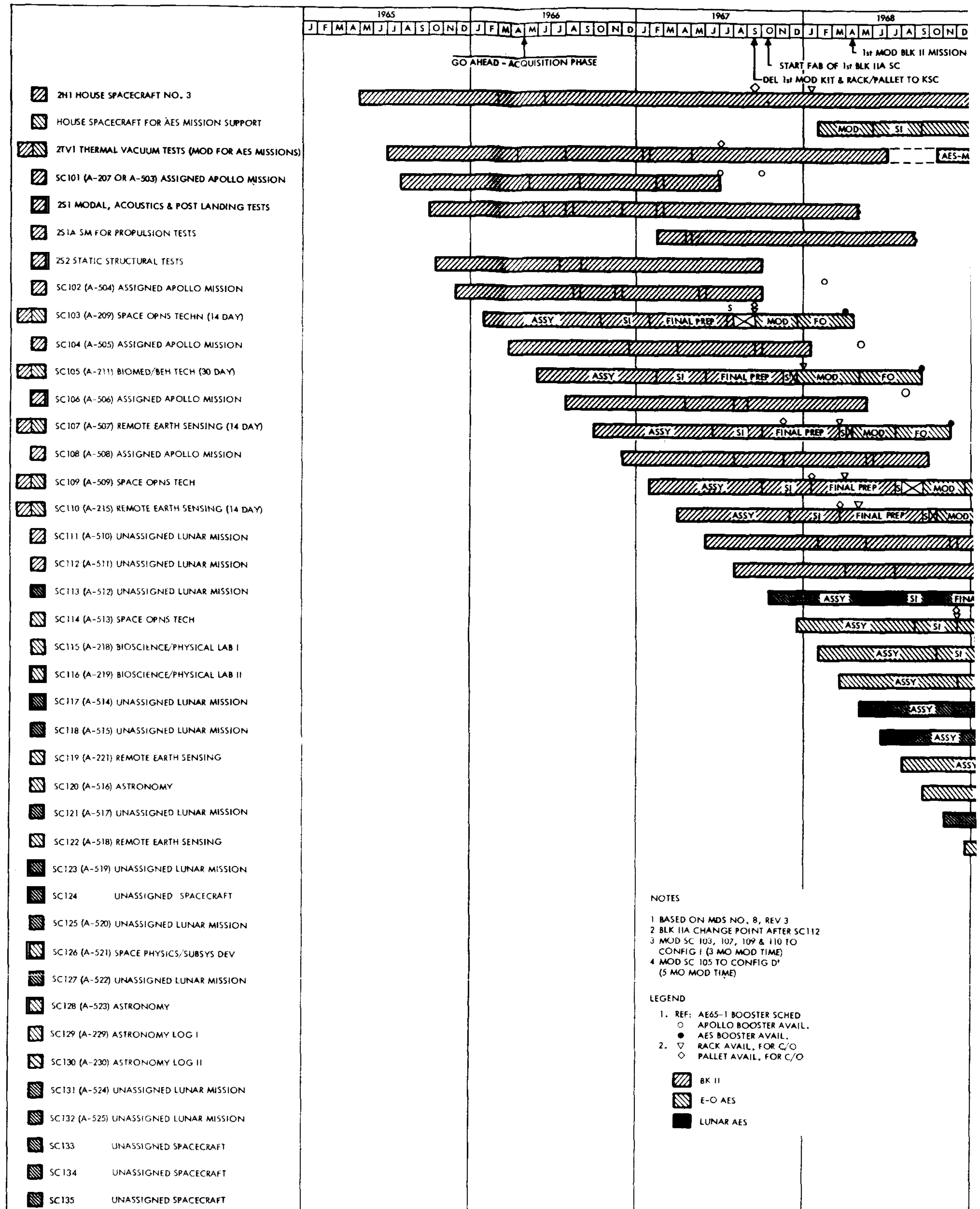
Block IIA span-times for assembly, systems installation, and final checkout are the same as on Block II. However, it is anticipated that subsequent experience in the Block II program will make it possible to apply yet unidentified learning factors that will reduce these time spans.

ALTERNATE SCHEDULE NO. 1

The alternate schedule (Figure 36 in Volume 5) is also based on an eight-per-year production rate, but assumes an earlier change point - i.e., on SC 108. This still leaves one Block II SC requiring modification at KSC, but any earlier change point would be considered imprudent. Times for design, development, production, and operations are the same as on the basic AES schedule, as well as on the Block II schedule. The assumed go-ahead date for Phase D is also the same -- 1 May 1966. The period available for development and qualification testing of Block IIA extended life subsystems, however (for which there was ample time allotted on the basic schedule), is reduced by approximately ten months, to a period consistent with the compressed development/qualification periods already allocated for pallet and rack, under either schedule. The impact on facilities is the same in either schedule; minor rearrangement would have to be made in the Installation and Checkout Building (290) at Downey to accommodate the rack and pallet and additional GSE for integrated checkout.

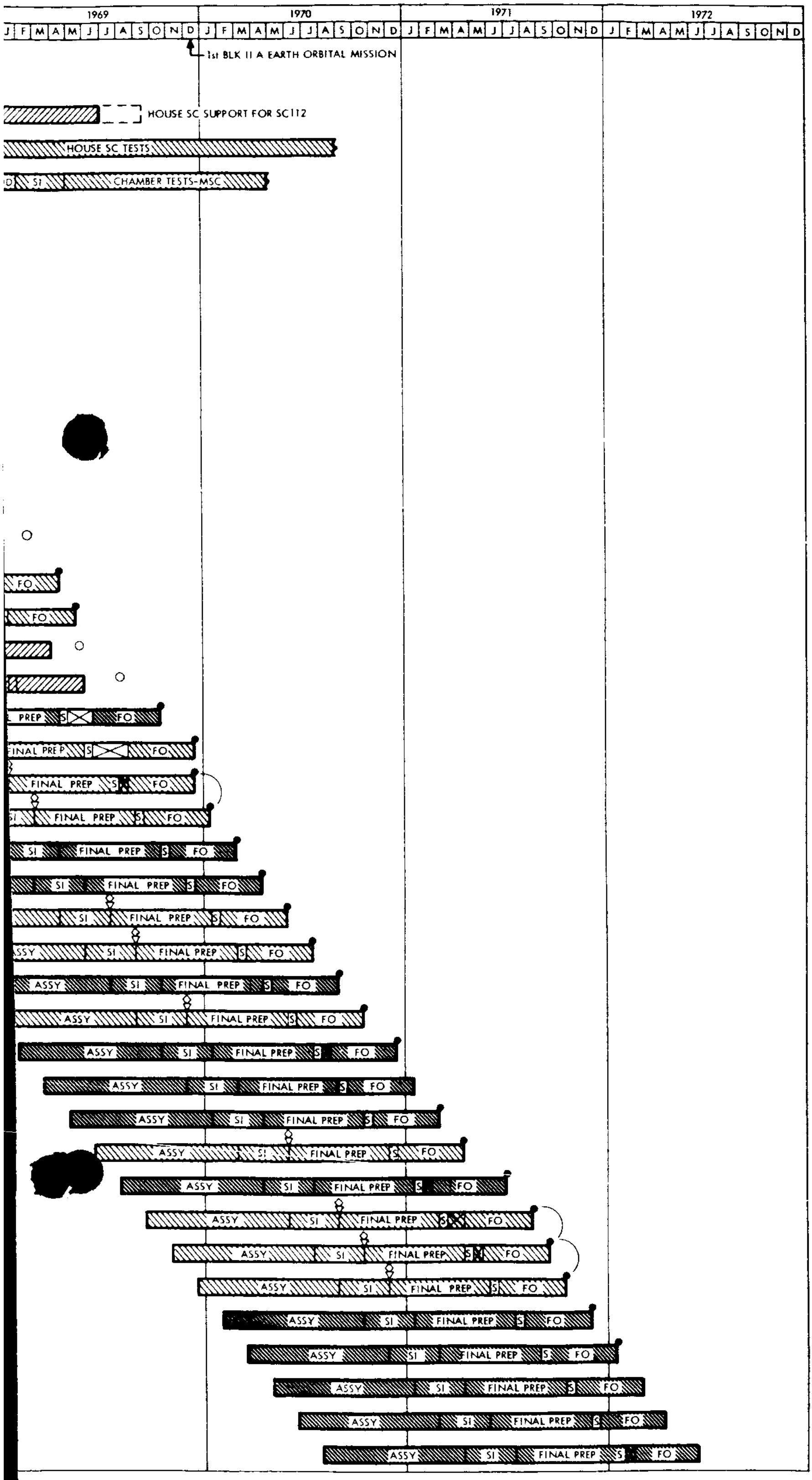
ANALYSIS AND CONCLUSION

Both basic and alternate schedules meet AES total program objectives with minimum interference to the Apollo lunar landing program, and present a feasible, logical, and systematic phasing and integration of interrelated program activities that capitalize on Apollo planning experience as well as the hardware and technology proved in the Apollo program. In both schedules, the development and qualification testing of new hardware is the most


1965
1966
1967
1968
J F M A M J J A S O N D
GO AHEAD - ACQUISITION PHASE
1st MOD BLK II MISSION
START FAB OF 1st BLK IIA SC
DEL 1st MOD KIT & RACK/PALLET TO KSC
2H1 HOUSE SPACECRAFT NO. 3
HOUSE SPACECRAFT FOR AES MISSION SUPPORT
2TV1 THERMAL VACUUM TESTS (MOD FOR AES MISSIONS)
SC101 (A-207 OR A-503) ASSIGNED APOLLO MISSION
2S1 MODAL, ACOUSTICS & POST LANDING TESTS
2S1A SM FOR PROPULSION TESTS
2S2 STATIC STRUCTURAL TESTS
SC102 (A-504) ASSIGNED APOLLO MISSION
SC103 (A-209) SPACE OPNS TECHN (14 DAY)
SC104 (A-505) ASSIGNED APOLLO MISSION
SC105 (A-211) BIOMED/BEH TECH (30 DAY)
SC106 (A-506) ASSIGNED APOLLO MISSION
SC107 (A-507) REMOTE EARTH SENSING (14 DAY)
SC108 (A-508) ASSIGNED APOLLO MISSION
SC109 (A-509) SPACE OPNS TECH
SC110 (A-215) REMOTE EARTH SENSING (14 DAY)
SC111 (A-510) UNASSIGNED LUNAR MISSION
SC112 (A-511) UNASSIGNED LUNAR MISSION
SC113 (A-512) UNASSIGNED LUNAR MISSION
SC114 (A-513) SPACE OPNS TECH
SC115 (A-218) BIOSCIENCE/PHYSICAL LAB I
SC116 (A-219) BIOSCIENCE/PHYSICAL LAB II
SC117 (A-514) UNASSIGNED LUNAR MISSION
SC118 (A-515) UNASSIGNED LUNAR MISSION
SC119 (A-221) REMOTE EARTH SENSING
SC120 (A-516) ASTRONOMY
SC121 (A-517) UNASSIGNED LUNAR MISSION
SC122 (A-518) REMOTE EARTH SENSING
SC123 (A-519) UNASSIGNED LUNAR MISSION
SC124 UNASSIGNED SPACECRAFT
SC125 (A-520) UNASSIGNED LUNAR MISSION
SC126 (A-521) SPACE PHYSICS/SUBSYS DEV
SC127 (A-522) UNASSIGNED LUNAR MISSION
SC128 (A-523) ASTRONOMY
SC129 (A-229) ASTRONOMY LOG I
SC130 (A-230) ASTRONOMY LOG II
SC131 (A-524) UNASSIGNED LUNAR MISSION
SC132 (A-525) UNASSIGNED LUNAR MISSION
SC133 UNASSIGNED SPACECRAFT
SC134 UNASSIGNED SPACECRAFT
SC135 UNASSIGNED SPACECRAFT
MOD
SI
AES-M
ASSY
FINAL PREP
FO
S
NOTES
1 BASED ON MDS NO. 8, REV 3
2 BLK IIA CHANGE POINT AFTER SC112
3 MOD SC 103, 107, 109 & 110 TO CONFIG I (3 MO MOD TIME)
4 MOD SC 105 TO CONFIG D' (5 MO MOD TIME)
LEGEND
1. REF: AE65-1 BOOSTER SCHED
○ APOLLO BOOSTER AVAIL.
● AES BOOSTER AVAIL.
2. ▽ RACK AVAIL. FOR C/O
◇ PALLET AVAIL. FOR C/O
BK II
E-O AES
LUNAR AES

7

Figure 31



. AES Basic Schedule (Eight-Per-Year Rate)

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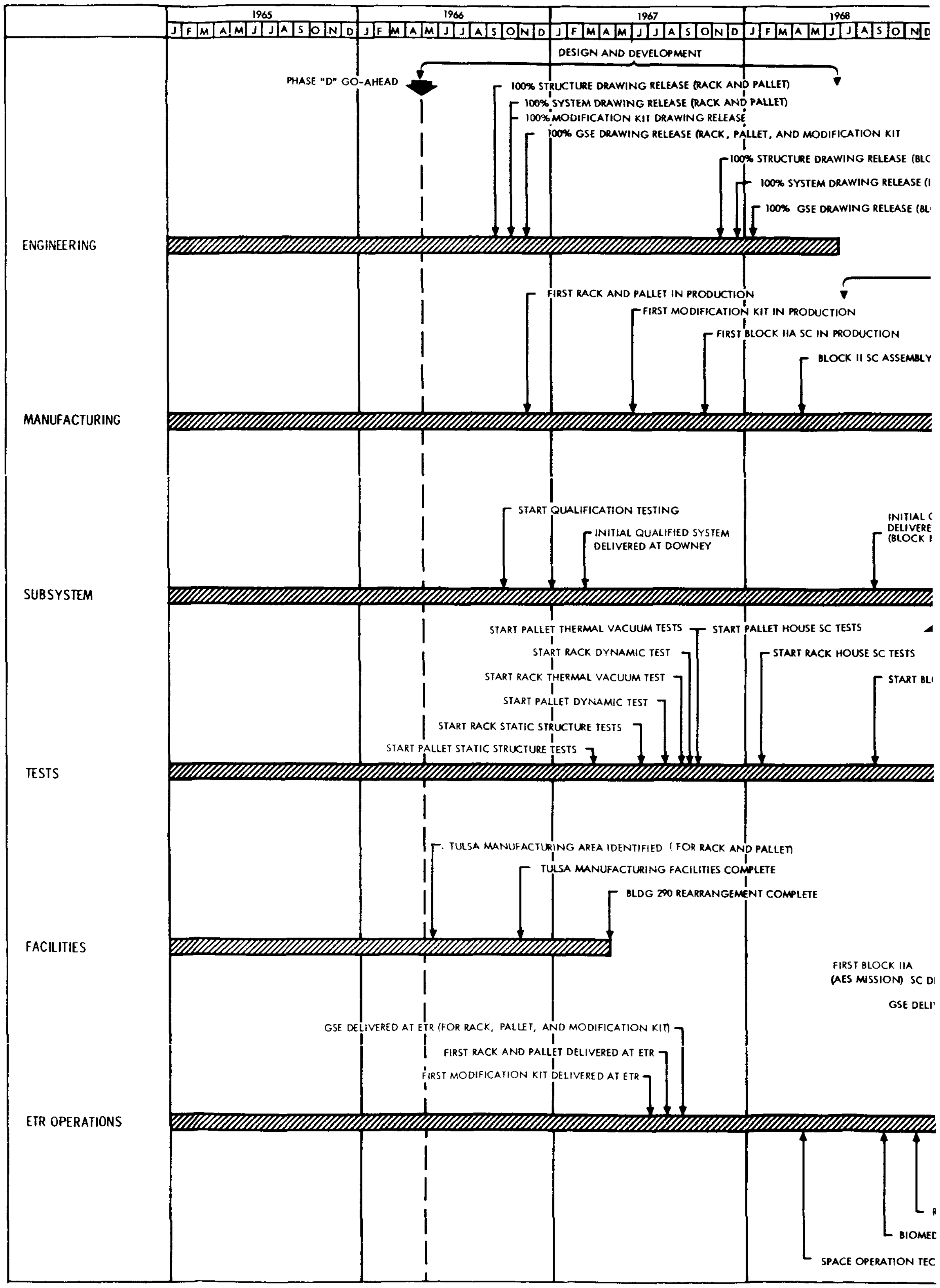
1965
1966
1967
1968
J F M A M J J A S O N D
DESIGN AND DEVELOPMENT
PHASE "D" GO-AHEAD
100% STRUCTURE DRAWING RELEASE (RACK AND PALLET)
100% SYSTEM DRAWING RELEASE (RACK AND PALLET)
100% MODIFICATION KIT DRAWING RELEASE
100% GSE DRAWING RELEASE (RACK, PALLET, AND MODIFICATION KIT
100% STRUCTURE DRAWING RELEASE (BLC
100% SYSTEM DRAWING RELEASE (I
100% GSE DRAWING RELEASE (BL
ENGINEERING
FIRST RACK AND PALLET IN PRODUCTION
FIRST MODIFICATION KIT IN PRODUCTION
FIRST BLOCK IIA SC IN PRODUCTION
BLOCK II SC ASSEMBLY
MANUFACTURING
START QUALIFICATION TESTING
INITIAL QUALIFIED SYSTEM DELIVERED AT DOWNEY
INITIAL (
DELIVERE
(BLOCK I
SUBSYSTEM
START PALLET THERMAL VACUUM TESTS
START PALLET HOUSE SC TESTS
START RACK DYNAMIC TEST
START RACK HOUSE SC TESTS
START RACK THERMAL VACUUM TEST
START BL
START PALLET DYNAMIC TEST
START RACK STATIC STRUCTURE TESTS
START PALLET STATIC STRUCTURE TESTS
TESTS
TULSA MANUFACTURING AREA IDENTIFIED (FOR RACK AND PALLET)
TULSA MANUFACTURING FACILITIES COMPLETE
BLDG 290 REARRANGEMENT COMPLETE
FACILITIES
FIRST BLOCK IIA
(AES MISSION) SC D
GSE DELI
GSE DELIVERED AT ETR (FOR RACK, PALLET, AND MODIFICATION KIT)
FIRST RACK AND PALLET DELIVERED AT ETR
FIRST MODIFICATION KIT DELIVERED AT ETR
ETR OPERATIONS
BIOMED
SPACE OPERATION TEC

(1)

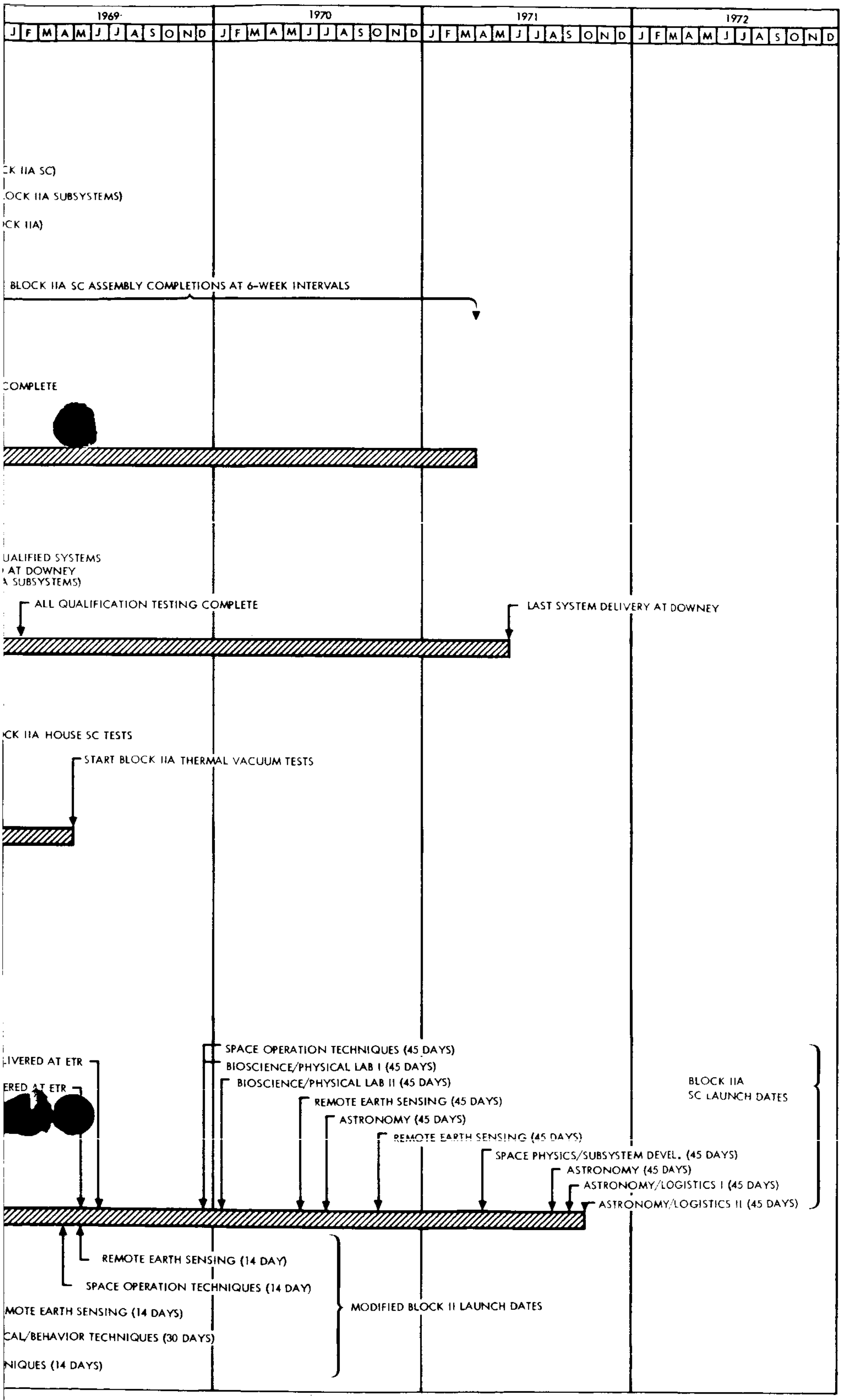

Figure 32. AES Program Major Milestones

schedule-critical activity, and has been compressed into the minimum acceptable period consistent with the phasing of other program elements. The basic schedule is considered more conservative, however, and is the one recommended for use on the AES program.

Acceleration of the production rate to 14 spacecraft per year is also feasible, but with additional cost in facilities, tooling, and checkout equipment.

AES PROGRAM COST

The major cost elements considered in this study include engineering design and development, materials, manufacturing, experiment installation, quality control, reliability, test operations, facilities, tooling, GSE, logistic support, and subcontracting.

Abbreviated descriptions of tasks to be performed during Phase D (only), were prepared during the AES study and used as an estimating base for establishing the factors for program costs that are presented in accompanying pages. (Preliminary design phase costs are not included.)

These tasks also were used in estimating the times that appear in the program schedules in this section and elsewhere in this study. They were developed in accordance with the concepts outlined in NPC 500-1, Apollo Configuration Management, and include system engineering, design engineering, interface control, program control, reliability engineering, quality control, test engineering, test operations, logistics, industrial engineering, facilities engineering, material, manufacturing, contract administration, and program management. For cost-estimating purposes, however, across-the-board tasks such as program management, configuration management, program control, etc., were distributed proportionately across the program hardware line items.

The costs presented in accompanying tables represent delta costs; to obtain total costs for accomplishing AES program missions, these costs must be added to the basic Apollo Block II costs at the eight-per-year production rate.

As in other aspects of the AES study, maximum advantage was taken in the cost analysis of the AES program of the data and experience available in the Apollo program, as well as previous studies of follow-on programs to the Apollo lunar landing program. Accordingly, these cost estimates may be evaluated with a considerably higher level of confidence than would be normal for such a highly compressed study effort.

Complete cost breakdowns in the detailed, NASA-prescribed formats have been prepared and are presented in Volume 5. Summary charts showing average delta cost per launch ($2,816,000) and delta facilities costs ($470,000 - separately identified, and not included in other cost analyses) are also presented in Volume 5. Total program delta costs ($359,601,000) over the eight-per-year Apollo Block II base are presented in Table 27.

Table 27. Summary of Total Program Delta Cost*

Item	Design and Development		Production		Total	
	Hours	Dollars	Hours	Dollars	Hours	Dollars
Engineering	5,741,000	$ 71,061,000	2,630,900	$ 30,590,000	8,371,900	$101,651,000
Manufacturing	1,469,200	20,674,000	5,170,100	55,728,000	6,639,300	76,402,000
Tooling	1,255,600	9,938,000	708,300	5,687,000	1,963,900	15,625,000
Subcontracting		34,258,000		88,461,000		122,719,000
GSE	417,600	5,735,000	251,400	3,331,000	669,000	9,066,000
Spares				13,735,000		13,735,000
Facilities		470,000				470,000
Total	8,883,400	$142,136,000	8,760,700	$197,532,000	17,644,100	$339,668,000
Operations					2,124,300	21,213,000
Grand Total	8,883,400	$142,136,000	8,760,700	$197,532,000	19,768,500	$360,881,000

*To be added to eight-per-year Block II Apollo base

Note: GFP (G&N) cost not included. Includes 5 modified Block II CSM's, 23 Block IIA CSM's, 37 racks, 32 pallets, 30 sets of rack and pallet subsystems.

CONCLUSIONS

The experiments integration analyses and corollary vehicle and subsystem design studies accomplished in this study have served to markedly increase the general understanding (confidence level) in the capability of postulated Apollo-extrapolated spacecraft to fulfill AES mission functions. As a result of the study, a number of signficant conclusions can be drawn; these are briefly stated in the following paragraphs. It is interesting to note that some of the conclusions actually are in opposition to prior beliefs, particularly as regards the suitability and operational effectiveness of certain candidate-system modular elements.

Due to the NASA-specified requirements that a three-man crew be employed on all AES flights, and because of other defined configurational change constraints, experimental volume available within the command module is essentially negligible. This fact is in sharp contrast to the two-man Apollo X study results derived previously. As a result, the CSM alone possesses essentially no ability to fulfill AES experimental functions—and some type of experimental appendage is absolutely required.

Earlier industry and government studies or orbital laboratories have generally tended toward providing the largest pressurized volumes possible. Studies conducted by S&ID (for NASA LRC) as early as 1961 on the Self-Deploying Space Station indicated, for example, an orbital laboratory design with over 50, 000 cubic feet of pressurized working and living space. More recent studies have tended toward reducing the volume; this trend is indicated in the MORL studies by Douglas and in the Apollo X laboratory module studies currently being conducted by Boeing. In the latter studies, the pressurized volume has been reduced to the order of 1200 to 1500 cubic feet. Prior to the AES study, orbital laboratory volumetric requirements have, for the most part, been only arbitrarily assumed. The preliminary experiments integration analyses that have been completed as part of this study have, however, yielded sharply contrasting results. All currently identified experimental requirements—both NASA and Air Force—firmly and absolutely require only a small pressurized section of approximately 200 cubic feet. A pressurized cell or airlock of this size is sufficient to accommodate two crewmen standing together with one functioning as a test subject (for biomedical and behavioral experiments) and the other as experimental observer. The same pressurized volume seems to be fully compatible with all other experimental control-and-display and work-space requirements attendant with AES and MOL activities. Further, the experimental integration analyses have shown that rather large areas and volumes adjacent to the small pressurized section are required for installation of sensory equipment and other experimental items that must be exposed to the space environment. Thus, in spite of earlier beliefs that large pressurized volumes and small unpressurized volumes were most desirable for manned orbital laboratories, the latest and most penetrating analyses have indicated the opposite situation to be true.

On the basis of such factors, the NASA experimental rack concept studied by S&ID appears to be an effective and operationally flexible experimental appendage. S&ID analyses have indicated that the rack/CSM combination could fulfill all of the 15 NASA-specified experimental flights with but minor discrepancies. The only variations required in the experimental program pertain to slight changes in the frequency of performance of a few minor biomedical experiments. These deviations were, in fact, attributable to propellant capacity limitations of the CSM, rather than to the rack itself. It must again be emphasized that because of the extremely short study duration, S&ID had no opportunity to actually perform a rack design optimization. The design which is presented in this study should be considered only as being representative; the few simple guidelines from which the design resulted can, however, be logically supported. For example, the height of the rack is determined primarily from the height of an erect crewman, the base diameter is established by the requirements to span the LEM attach points in the adapter section, etc.

The experiments pallet previously defined under contract NAS9-3923 was found to have relatively low utility or applicability to specified AES experimental missions. The pallet could not accommodate a significant portion of the experimental packages of interest and the use of a larger experimental appendage such as the rack was essential. It is possible to use the pallet in combination with the rack, but such an approach seems most ineffective, since the latter alone appears capable of fulfilling all needed experimental requirements. It should be emphasized, however, that the pallet concept is basically a sound one and such a device may in fact be meaningful for use in non-AES Apollo flights where the experimental demands are relatively slight.

The spacecraft and subsystem variations identified as Configurations C and D were fully and equivalently applied against the AES mission demands. Configuration C, which is essentially the Apollo X approach (wherein subsystem life extension provisions are included within the CSM itself), consistently appears more effective from an operational standpoint. More experimental functions can be accommodated and/or longer mission durations achieved than are possible with Configuration D. This fact is mainly attributable to the Configuration D weight penalty (which ranges from 2000 to 4000 pounds), which results from carrying fuel cells and cryogenic tanks both in the experimental appendage and in the service module, rather than in the latter alone. Additionally, the SPS tankage could be varied according to mission requirements in Configuration C, whereas in Configuration D, NASA-specified constraints of no or minimum changes to the CSM precluded such weight savings. In summary, and of most significance, is the fact that Configuration D is very likely <u>not</u> suitable for the lunar missions aspects of the AES program. Since the power system and other subsystem life extension provisions are included in the experimental appendage, the entire experiments module would have to be returned from lunar orbit with the CSM to provide for the transearth return phase (2-1/2 to 4-1/2 days); this capability is not available within the Apollo service propulsion system capacity, nor can simple modifications be made to solve this problem. It still remains, however, for further development planning studies to determine whether the Configuration D type of approach should be utilized as an interim step, or whether it is more meaningful to proceed directly with the development of the Configuration C type of spacecraft.